ENCLOSURE 1

WATTS BAR NUCLEAR PLANT UNIT 1
WCAP-16245-NP, REVISION 0
ANALYSIS OF CAPSULE X FROM THE
TENNESSEE VALLEY AUTHORITY, WATTS BAR UNIT 1
REACTOR VESSEL RADIATION SURVEILLANCE PROGRAM

Westinghouse Non-Proprietary Class 3

WCAP-16245-NP
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Analysis of Capsule X from the Tennessee Valley Authority, Watts Bar Unit 1 Reactor Vessel Radiation Surveillance Program

Westinghouse

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PREFACE

This report has been technically reviewed and verified by:

Reviewer:

Sections 1 through 5, 7, 8, Appendices B, C and D	C.M. Burton	CMBurton
Section 6 and Appendix A	S.L. Anderson	S.L.Anderson

EXECUTIVE SUMMARY

The purpose of this report is to document the results of the testing of surveillance Capsule X from Watts Bar Unit 1. Capsule X was removed at 6.63 EFPY and post irradiation mechanical tests of the Charpy V-notch and tensile specimens were performed. A fluence evaluation utilizing the recently released neutron transport and dosimetry cross-section libraries was derived from the ENDF/B-VI data-base. Capsule X received a fluence of 1.71×10^{19} n/cm^2 after irradiation to 6.63 EFPY. The peak clad/base metal interface vessel fluence after 6.63 EFPY of plant operation was 3.39×10^{18} n/cm^2.

This evaluation lead to the following conclusions: 1) The measured 30 ft-lb shift in transition temperature values of the Intermediate Shell Forging 05 contained in capsule X (Tangential & Axial) is less than the Regulatory Guide 1.99, Revision 2[1], predictions. 2) The measured 30 ft-lb shift in transition temperature values of the weld metal contained in capsule X is less than the Regulatory Guide 1.99, Revision 2, predictions. 3) The measured percent decrease in upper shelf energy for all the surveillance materials of Capsules X contained in the Watts Bar Unit 1 surveillance program are less than the Regulatory Guide 1.99, Revision 2 predictions. 4) The lower shell forging and the intermediate shell to lower shell girth weld materials exhibit a more than adequate upper shelf energy level for continued safe plant operation and are predicted to maintain an upper shelf energy greater than 50 ft-lb throughout the life of the vessel (32 EFPY) as required by 10CFR50, Appendix G [2]. 5) The intermediate shell forging 05 is predicted to drop below 50 ft-lbs at 32 EFPY, however, it still remains above the 43 ft-lb lower bound as determined in WCAP-13587, Rev. 1[6]. 6) The Watts Bar Unit 1 surveillance weld data was found to be credible, while the surveillance forging 05 material was found to be not-credible. This evaluation can be found in Appendix D.

Lastly, a brief summary of the Charpy V-notch testing can be found in Section 1. All Charpy V-notch data was plotted using a symmetric hyperbolic tangent curve fitting program.

1 SUMMARY OF RESULTS

The analysis of the reactor vessel materials contained in surveillance Capsule X, the third capsule removed and tested from the Watts Bar Unit 1 reactor pressure vessel, led to the following conclusions:

- The Charpy V-notch data presented in BWXT Report dated 9/10/01[3] were based on a re-plot of all capsule data from WCAP-9298, Rev. 3[4] and WCAP-15046[5] using CVGRAPH, Version 5.0, which is a symmetric hyperbolic tangent curve-fitting program. The results presented here are also a re-plot from all the capsules because CVGRAPH has been updated to Version 5.0.2. Appendix C presents the CVGRAPH, Version 5.0.2, Charpy V-notch plots and the program input data.

- Capsule X received an average fast neutron fluence (E> 1.0 MeV) of 1.71×10^{19} n/cm^2 after 6.63 effective full power years (EFPY) of plant operation.

- Irradiation of the reactor vessel Intermediate Shell Forging 05 (heat number 527536) Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction (tangential orientation), resulted in an irradiated 30 ft-lb transition temperature of 37.6°F and an irradiated 50 ft-lb transition temperature of 87.2°F. This results in a 30 ft-lb transition temperature increase of 94.7°F and a 50 ft-lb transition temperature increase of 102.6°F for the longitudinal oriented specimens. See Table 5-9.

- Irradiation of the reactor vessel Intermediate Shell Forging 05 (heat number 527536) Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction (axial orientation), resulted in an irradiated 30 ft-lb transition temperature of 161.1°F and an irradiated 50 ft-lb transition temperature of 218.3°F. This results in a 30 ft-lb transition temperature increase of 115.9°F and a 50 ft-lb transition temperature increase of 104.1°F for the longitudinal oriented specimens. See Table 5-9.

- Irradiation of the weld metal (heat number 895075) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of -5.4°F and an irradiated 50 ft-lb transition temperature of 37.9°F. This results in a 30 ft-lb transition temperature increase of 25.8°F and a 50 ft-lb transition temperature increase of 43.8°F. See Table 5-9.

- Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 18.6°F and an irradiated 50 ft-lb transition temperature of 62.5°F. This results in a 30 ft-lb transition temperature increase of 74.8°F and a 50 ft-lb transition temperature increase of 71.1°F. See Table 5-9.

- The average upper shelf energy of the Intermediate Shell Forging 05 (tangential orientation) resulted in an average energy decrease of 26 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 106 ft-lb for the longitudinal oriented specimens. See Table 5-9.

- The average upper shelf energy of the Intermediate Shell Forging 05 (axial orientation) resulted in no energy decrease after irradiation. This results in an irradiated average upper shelf energy of 62 ft-lb for the tangential oriented specimens. See Table 5-9.

- The average upper shelf energy of the weld metal Charpy specimens resulted in no energy decrease after irradiation. This results in an irradiated average upper shelf energy of 131 ft-lb for the weld metal specimens. See Table 5-9.

- The average upper shelf energy of the weld HAZ metal Charpy specimens resulted in an average energy decrease of 9 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 80 ft-lb for the weld HAZ metal. See Table 5-9.

- A comparison, as presented in Table 5-10, of the Watts Bar Unit 1 reactor vessel surveillance material test results with the Regulatory Guide 1.99, Revision 2[1] predictions led to the following conclusions:

  — The measured 30 ft-lb shift in transition temperature values of the Intermediate Shell Forging 05 contained in capsule X (longitudinal & transverse) are less than the Regulatory Guide 1.99, Revision 2, predictions.

  — The measured 30 ft-lb shift in transition temperature value of the weld metal contained in capsule X is less than the Regulatory Guide 1.99, Revision 2, predictions.

  — The measured percent decrease in upper shelf energy for all the surveillance materials of Capsules X contained in the Watts Bar Unit 1 surveillance program are less than the Regulatory Guide 1.99, Revision 2 predictions.

- The calculated end-of-license (32 EFPY) neutron fluence (E> 1.0 MeV) at the core midplane for the Watts Bar Unit 1 reactor vessel using the Regulatory Guide 1.99, Revision 2 attenuation formula (i.e., Equation #3 in the guide) are as follows:

<u>Calculated:</u> Vessel inner radius* = 1.541×10^{19} n/cm^2

Vessel 1/4 thickness = 9.27×10^{18} n/cm^2

Vessel 3/4 thickness = 3.36×10^{18} n/cm^2

*Clad/base metal interface. (From Table 6-2)

- All beltline materials, with exception to the intermediate shell forging 05, are expected to have an upper shelf energy (USE) greater than 50 ft-lb through end of license (EOL, 32 EFPY) as required by 10CFR50, Appendix G[2].

  In September of 1993, Westinghouse completed an evaluation to demonstrate that all Westinghouse Owners Group (WOG) Plant reactor vessels have a margin of safety, relative to USE, equivalent to that required by Appendix G of the ASME Code. This was accomplished by performing generic bounding evaluations per the proposed ASME Section XI, Appendix X. This evaluation is documented in WCAP-13587, Revision 1[6], "Reactor Vessel Upper Shelf Energy Bounding Evaluation for Westinghouse Pressurized Water Reactors" and provides the minimum USE for a four loop Westinghouse NSSS plant. The minimum acceptable USE for a 4 loop plant is 43 ft-lb. The projected minimum EOL USE for the Watts Bar Unit 1 intermediate shell forging 05 is greater than 43 ft-lb. Hence, the bounding WOG evaluation shows that the Watts Bar Unit 1 intermediate shell forging 05 will maintain an equivalent margin, with respect to USE per the requirements of 10 CFR Part 50, Appendix G, through EOL (i.e. Maintain this margin through EOL). In addition, the results of capsule X testing indicate that the measured EOL USE for the axially oriented Charpy specimens actually increased by approximately 4 ft-lb.

  In addition, as part of the Capsule W testing, Framatome performed 1/2T compact tension tests to determine the upper shelf J-R curve for the intermediate shell forging 05. The purpose of this test was to demonstrate that the Watts Bar Unit 1 reactor vessel has margins of safety equivalent to the ASME Code Appendix G. The results were that the low upper shelf for intermediate shell forging 05 had sufficient margin. Lastly, as part of this capsule testing, Westinghouse will be performing a similar test and analysis, with the same purpose as that was previously performed by Framatome. This report will be published following the issuance of this report.

2 INTRODUCTION

This report presents the results of the examination of Capsule X, the third capsule removed from the reactor in the continuing surveillance program which monitors the effects of neutron irradiation on the Watts Bar Unit 1 reactor pressure vessel materials under actual operating conditions.

The surveillance program for the Watts Bar Unit 1 reactor pressure vessel materials was designed and recommended by the Westinghouse Electric Corporation. A description of the surveillance program and the pre-irradiation mechanical properties of the reactor vessel materials are presented in WCAP-9298, "Tennessee Valley Authority Watts Bar Unit No. 1 Reactor Vessel Radiation Surveillance Program"[4]. The surveillance program was planned to cover the 40-year design life of the reactor pressure vessel and was based on ASTM E185-73[9], "Standard Recommended Practice Surveillance Tests for Nuclear Reactor Vessels." Capsule X was removed from the reactor after 6.63 EFPY of exposure and shipped to the Westinghouse Science and Technology Department Hot Cell Facility, where the post-irradiation mechanical testing of the Charpy V-notch impact and tensile surveillance specimens was performed.

This report summarizes the testing of and the post-irradiation data obtained from surveillance capsule X removed from the Watts Bar Unit 1 reactor vessel and discusses the analysis of the data.

3 BACKGROUND

The ability of the large steel pressure vessel containing the reactor core and its primary coolant to resist fracture constitutes an important factor in ensuring safety in the nuclear industry. The beltline region of the reactor pressure vessel is the most critical region of the vessel because it is subjected to significant fast neutron bombardment. The overall effects of fast neutron irradiation on the mechanical properties of low alloy, ferritic pressure vessel steels such as A508 Class 2 Forging (base material of the Watts Bar Unit 1 reactor pressure vessel beltline) are well documented in the literature. Generally, low alloy ferritic materials show an increase in hardness and tensile properties and a decrease in ductility and toughness during high-energy irradiation.

A method for ensuring the integrity of reactor pressure vessels has been presented in "Fracture Toughness Criteria for Protection Against Failure," Appendix G to Section XI of the ASME Boiler and Pressure Vessel Code[8]. The method uses fracture mechanics concepts and is based on the reference nil-ductility transition temperature (RT_{NDT}).

RT_{NDT} is defined as the greater of either the drop weight nil-ductility transition temperature (NDTT per ASTM E-208[7]) or the temperature 60°F less than the 50 ft-lb (and 35-mil lateral expansion) temperature as determined from Charpy specimens oriented perpendicular (transverse) to the major working direction of the plate. The RT_{NDT} of a given material is used to index that material to a reference stress intensity factor curve (K_{Ic} curve) which appears in Appendix G to the ASME Code[7]. The K_{Ic} curve is a lower bound of static fracture toughness results obtained from several heats of pressure vessel steel. When a given material is indexed to the K_{Ic} curve, allowable stress intensity factors can be obtained for this material as a function of temperature. Allowable operating limits can then be determined using these allowable stress intensity factors.

RT_{NDT} and, in turn, the operating limits of nuclear power plants can be adjusted to account for the effects of radiation on the reactor vessel material properties. The changes in mechanical properties of a given reactor pressure vessel steel, due to irradiation, can be monitored by a reactor vessel surveillance program, such as the Watts Bar Unit 1 reactor vessel radiation surveillance program[4], in which a surveillance capsule is periodically removed from the operating nuclear reactor and the encapsulated specimens tested. The increase in the average Charpy V-notch 30 ft-lb temperature (ΔRT_{NDT}) due to irradiation is added to the initial RT_{NDT}, along with a margin (M) to cover uncertainties, to adjust the RT_{NDT} (ART) for radiation embrittlement. This ART (RT_{NDT} initial + M + ΔRT_{NDT}) is used to index the material to the K_{Ic} curve and, in turn, to set operating limits for the nuclear power plant that take into account the effects of irradiation on the reactor vessel materials.

4 DESCRIPTION OF PROGRAM

Six surveillance capsules for monitoring the effects of neutron exposure on the Watts Bar Unit 1 reactor pressure vessel core region (beltline) materials were inserted in the reactor vessel prior to initial plant start-up. The six capsules were positioned in the reactor vessel between the neutron pads and the vessel wall as shown in Figure 4-1. The vertical center of the capsules is opposite the vertical center of the core.

Capsule X was removed after 6.63 effective full power years (EFPY) of plant operation. This capsule contained Charpy V-notch, tensile, and 1/2T-CT fracture mechanics specimens made from intermediate shell forging 05 (heat number 527536) and submerged arc weld metal identical to the reactor vessel beltline region weld. In addition, this capsule contained Charpy V-notch specimens from the weld Heat-Affected-Zone (HAZ) metal of intermediate shell forging 05.

Test material obtained from the intermediate shell forging 05 (after thermal heat treatment and forming of the plate) was taken at least one plate thickness from the quenched edges of the plate. All test specimens were machined from the ¼ thickness location of the plate after performing a simulated post-weld stress-relieved weldment joining intermediate shell forging 05 and adjacent lower shell forging 04. All heat-affected-zone specimens were obtained from the weld heat-affected-zone of the intermediate shell forging 05.

Charpy V-notch impact specimens from intermediate shell forging 05 were machined in the tangential orientation (longitudinal axis of the specimen parallel to the major working direction) and also in the axial orientation (longitudinal axis of the specimen perpendicular to the major working direction). The core region weld Charpy impact specimens were machined from the weldment such that the long dimension of each Charpy specimen was perpendicular to the weld direction. The notch of the weld metal Charpy specimens was machined such that the direction of crack propagation in the specimen was in the welding direction.

Tensile specimens from the intermediate shell forging 05 were machined in both the tangential and axial orientations. Tensile specimens from the weld metal were oriented with the long dimension of the specimen perpendicular to the weld direction.

Bend bar specimens were machined from the intermediate shell forging 05 with the longitudinal axis of the specimen oriented in the rolling direction of the forging such that the simulated crack would propagate in a direction normal to the rolling direction of the forging. All bend bar specimens were fatigue pre-cracked according to ASTM E399.

Compact tension test specimens from intermediate shell forging 05 were machined in the tangential and axial orientations. Compact tension test specimens from the weld metal were machined perpendicular to the weld direction with the notch oriented in the direction of welding. All specimens were fatigue pre-cracked according to ASTM E399.

The chemical composition and heat treatment of the unirradiated surveillance materials are presented in Tables 4-1 and 4-2, respectively. The data in Table 4-1 and 4-2 was obtained from the unirradiated surveillance program report, WCAP-9298, Rev. 3, Appendix A.

Capsule X contained dosimeter wires of pure iron, copper, nickel, and aluminum 0.15 weight percent cobalt (cadmium-shielded and unshielded). In addition, cadmium shielded dosimeters of neptunium (Np^{237}) and uranium (U^{238}) were placed in the capsule to measure the integrated flux at specific neutron energy levels.

The capsule contained thermal monitors made from two low-melting-point eutectic alloys and sealed in Pyrex tubes. These thermal monitors were used to define the maximum temperature attained by the test specimens during irradiation. The composition of the two eutectic alloys and their melting points are as follows:

2.5% Ag, 97.5% Pb	Melting Point: 579°F (304°C)
1.75% Ag, 0.75% Sn, 97.5% Pb	Melting Point: 590°F (310°C)

The arrangement of the various mechanical specimens, dosimeters and thermal monitors contained in Capsule X is shown in Figure 4-2.

Table 4-1 Chemical Composition (wt%) of the Watts Bar Unit 1 Reactor Vessel Surveillance Materials (Unirradiated)[a]

Element	Intermediate Shell Forging 05[a]		Weld Metal[b & c]	
C	0.20	0.21	0.080	0.069
S	0.016	0.014	0.007	0.010
N	0.009	---	0.019	---
Co	<0.01	0.012	0.007	---
Cu	0.17	0.14	0.031	0.05
Si	0.25	0.25	0.27	0.22
Mo	0.57	0.61	0.54	0.56
Ni	0.80	0.79	0.75	0.70
Mn	0.73	0.68	1.94	1.97
Cr	0.32	0.34	0.023	0.05
V	<0.01	<0.02	0.001	---
P	0.012	0.013	0.015	0.010
Al	<0.019	0.049	0.019	---
Sn	0.010	---	0.003	---

Notes:

(a) All analysis except for N and Sn were conducted by Rotterdam Dockyard Company/Krupp ladle analysis; N and Sn analysis were performed by Westinghouse.

(b) The surveillance weldment is identical to the closing girth seam weldment between forging 04 and 05. The closing seam used weld wire heat number 895075 with Grau L.O. (LW320) flux, lot P46, except for the 1-inch root pass at the ID of the vessel. This root pass used weld wire heat number 899680 with type Grau L.O. (LW320) flux, lot P23, with as-deposited copper and phosphorus content of 0.03 and 0.009, respectively. The surveillance weldment specimens were not removed from this root area.

(c) The left column results were obtained from Westinghouse analyses, while the results in the right column results were obtained from analyses conducted by Rotterdam Dockyard Company.

Table 4-2 Heat Treatment History of the Watts Bar Unit 1 Reactor Vessel Surveillance Materials[(a)]			
Material	**Temperature (°F)**	**Time**	**Coolant**
Intermediate Shell Forging 05	1675 - 1700	3 ½	Water-quenched
	1230 - 1240	6	Air Cooled
	1140 ± 25	21	Furnace Cooled
Weldment	1140 ± 25	14 hr., 56 min	Furnace Cooled

Notes:

(a) This table was taken from WCAP-9298, Rev. 3[4].

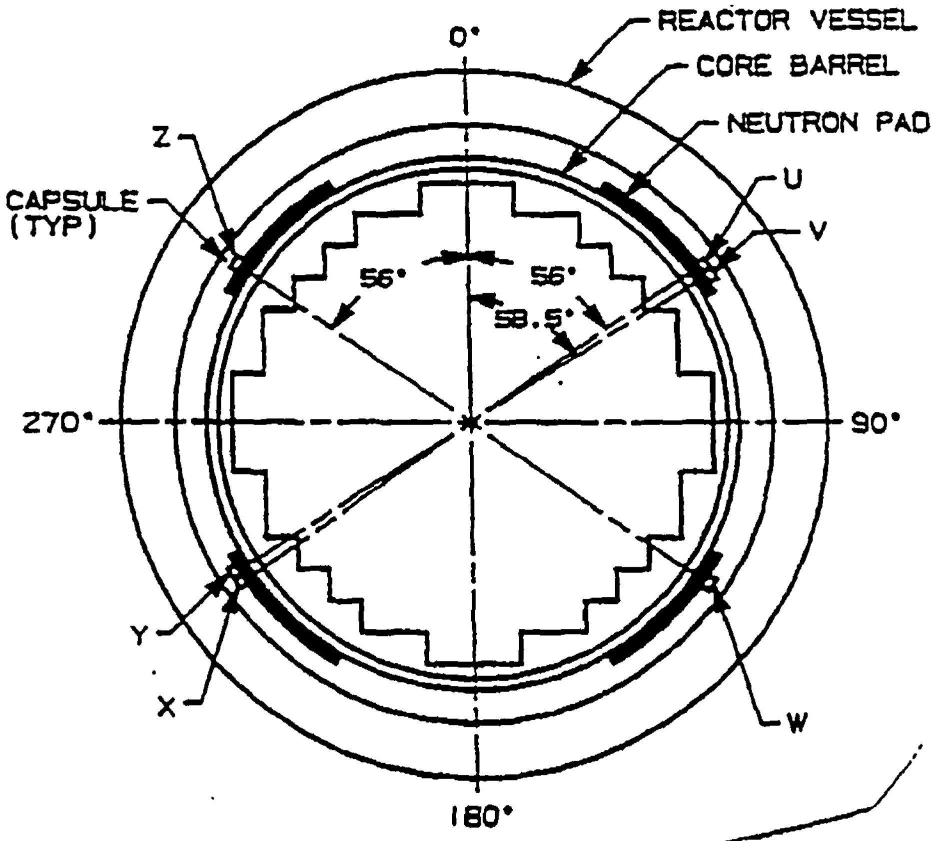


Figure 4-1 Arrangement of Surveillance Capsules in the Watts Bar Unit 1 Reactor Vessel

LEGEND: WL – INTERMEDIATE SHELL FORGING 05, HEAT NO. 527638 (TANGENTIAL)
WT – INTERMEDIATE SHELL FORGING 05, HEAT NO. 527638 (AXIAL)
WW – WELD METAL (HEAT # 895075)
WH – HEAT AFFECTED ZONE MATERIAL

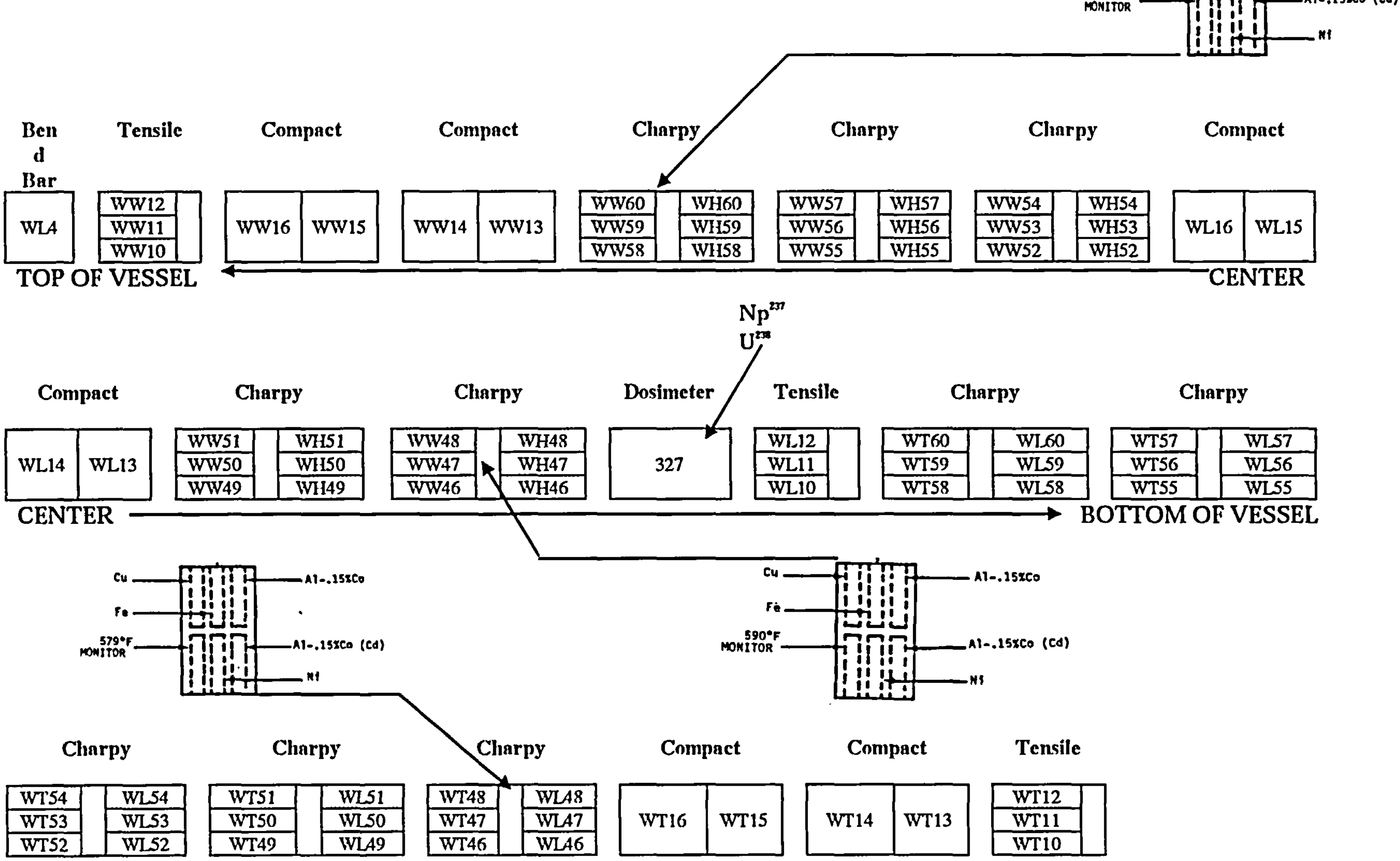


Figure 4-2 Capsule X Diagram Showing The Location of Specimens, Thermal Monitors, and Dosimeters

5 TESTING OF SPECIMENS FROM CAPSULE X

5.1 OVERVIEW

The post-irradiation mechanical testing of the Charpy V-notch impact specimens and tensile specimens was performed in the Remote Metallographic Facility (RMF) at the Westinghouse Science and Technology Center. Testing was performed in accordance with 10CFR50, Appendices G and H[2], ASTM Specification E185-82[9], and Westinghouse Procedure RMF 8402[10], Revision 2 as modified by Westinghouse RMF Procedures 8102[11], Revision 1, and 8103[12], Revision 1.

Upon receipt of the capsule at the hot cell laboratory, the specimens and spacer blocks were carefully removed, inspected for identification number, and checked against the master list in WCAP-9298, Rev. 3[4]. No discrepancies were found.

Examination of the two low-melting point 579°F (304°C) and 590°F (310°C) eutectic alloys indicated no melting of either type of thermal monitor. Based on this examination, the maximum temperature to which the test specimens were exposed was less than 579°F (304°C).

The Charpy impact tests were performed per ASTM Specification E23-02a[13] and RMF Procedure 8103 on a Tinius-Olsen Model 74, 358J machine. The tup (striker) of the Charpy impact test machine is instrumented with a GRC 930-I instrumentation system, feeding information into an IBM compatible computer. With this system, load-time and energy-time signals can be recorded in addition to the standard measurement of Charpy energy (E_D). From the load-time curve (Appendix B), the load of general yielding (P_{GY}), the time to general yielding (t_{GY}), the maximum load (P_M), and the time to maximum load (t_M) can be determined. Under some test conditions, a sharp drop in load indicative of fast fracture was observed. The load at which fast fracture was initiated is identified as the fast fracture load (P_F), and the load at which fast fracture terminated is identified as the arrest load (P_A).

The energy at maximum load (E_M) was determined by comparing the energy-time record and the load-time record. The energy at maximum load is approximately equivalent to the energy required to initiate a crack in the specimen. Therefore, the propagation energy for the crack (E_p) is the difference between the total energy to fracture (E_D) and the energy at maximum load (E_M).

The yield stress (σ_Y) was calculated from the three-point bend formula having the following expression:

$$\sigma_Y = (P_{GY} * L) / [B * (W - a)^2 * C] \tag{1}$$

where: L = distance between the specimen supports in the impact machine
B = the width of the specimen measured parallel to the notch
W = height of the specimen, measured perpendicularly to the notch
a = notch depth

The constant C is dependent on the notch flank angle (ϕ), notch root radius (ρ) and the type of loading (i.e., pure bending or three-point bending). In three-point bending, for a Charpy specimen in which ϕ = 45° and ρ = 0.010 inch, Equation 1 is valid with C = 1.21. Therefore, (for L = 4W),

$$\sigma_Y = (P_{GY} * L) / [B * (W - a)^2 * 1.21] = (3.305 * P_{GY} * W) / [B * (W - a)^2] \quad (2)$$

For the Charpy specimen, B = 0.394 inch, W = 0.394 inch and a = 0.079 inch. Equation 2 then reduces to:

$$\sigma_Y = 33.3 * P_{GY} \quad (3)$$

where σ_y is in units of psi and P_{GY} is in units of lbs. The flow stress was calculated from the average of the yield and maximum loads, also using the three-point bend formula.

The symbol A in columns 4, 5, and 6 of Tables 5-5 through 5-8 is the cross-section area under the notch of the Charpy specimens:

$$A = B * (W - a) = 0.1241 \text{ sq.in.} \quad (4)$$

Percent shear was determined from post-fracture photographs using the ratio-of-areas methods in compliance with ASTM Specification E23-98 and A370-97a[14]. The lateral expansion was measured using a dial gage rig similar to that shown in the same specification.

Tensile tests were performed on a 20,000-pound Instron, split-console test machine (Model 1115) per ASTM Specification E8-01[15] and E21-92 (1998)[16], and Procedure RMF 8102. All pull rods, grips, and pins were made of Inconel 718. The upper pull rod was connected through a universal joint to improve axiality of loading. The tests were conducted at a constant crosshead speed of 0.05 inches per minute throughout the test.

Extension measurements were made with a linear variable displacement transducer extensometer. The extensometer knife-edges were spring-loaded to the specimen and operated through specimen failure. The extensometer gage length was 1.00 inch. The extensometer is rated as Class B-2 per ASTM E83-93[17].

Elevated test temperatures were obtained with a three-zone electric resistance split-tube furnace with a 9-inch hot zone. All tests were conducted in air. Because of the difficulty in remotely attaching a thermocouple directly to the specimen, the following procedure was used to monitor specimen temperatures. Chromel-Alumel thermocouples were positioned at the center and at each end of the gage section of a dummy specimen and in each tensile machine griper. In the test configuration, with a slight load on the specimen, a plot of specimen temperature versus upper and lower tensile machine griper and controller temperatures was developed over the range from room temperature to 550°F. During the actual testing, the grip temperatures were used to obtain desired specimen temperatures. Experiments have indicated that this method is accurate to $\pm$2°F.

The yield load, ultimate load, fracture load, total elongation, and uniform elongation were determined directly from the load-extension curve. The yield strength, ultimate strength, and fracture strength were calculated using the original cross-sectional area. The final diameter and final gage length were determined from post-fracture photographs. The fracture area used to calculate the fracture stress (true stress at fracture) and percent reduction in area was computed using the final diameter measurement.

5.2 CHARPY V-NOTCH IMPACT TEST RESULTS

The results of the Charpy V-notch impact tests performed on the various materials contained in Capsule X, which received a fluence of 1.71 x 10^{19} n/cm^2(E> 1.0 MeV) in 6.63 EFPY of operation, are presented in Tables 5-1 through 5-11 and are compared with unirradiated results[4] as shown in Figures 5-1 through 5-12.

The transition temperature increases and upper shelf energy decreases for the Capsule X materials are summarized in Table 5-9 and led to the following results:

Irradiation of the reactor vessel Intermediate Shell Forging 05 (heat number 527536) Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction (tangential orientation), resulted in an irradiated 30 ft-lb transition temperature of 37.6°F and an irradiated 50 ft-lb transition temperature of 87.2°F. This results in a 30 ft-lb transition temperature increase of 94.7°F and a 50 ft-lb transition temperature increase of 102.6°F for the longitudinal oriented specimens.

Irradiation of the reactor vessel Intermediate Shell Forging 05 (heat number 527536) Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction (axial orientation), resulted in an irradiated 30 ft-lb transition temperature of 161.1°F and an irradiated 50 ft-lb transition temperature of 218.3°F. This results in a 30 ft-lb transition temperature increase of 115.9°F and a 50 ft-lb transition temperature increase of 104.1°F for the longitudinal oriented specimens.

Irradiation of the weld metal (heat number 895075) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of -5.4°F and an irradiated 50 ft-lb transition temperature of 37.9°F. This results in a 30 ft-lb transition temperature increase of 25.8°F and a 50 ft-lb transition temperature increase of 43.8°F.

Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 18.6°F and an irradiated 50 ft-lb transition temperature of 62.5°F. This results in a 30 ft-lb transition temperature increase of 74.8°F and a 50 ft-lb transition temperature increase of 71.1°F.

The average upper shelf energy of the Intermediate Shell Forging 05 (tangential orientation) resulted in an average energy decrease of 26 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 106 ft-lb for the longitudinal oriented specimens.

The average upper shelf energy of the Intermediate Shell Forging 05 (axial orientation) resulted in no energy decrease after irradiation. This results in an irradiated average upper shelf energy of 62 ft-lb for the tangential oriented specimens.

The average upper shelf energy of the weld metal Charpy specimens resulted in no energy decrease after irradiation. This results in an irradiated average upper shelf energy of 131 ft-lb for the weld metal specimens.

The average upper shelf energy of the weld HAZ metal Charpy specimens resulted in an average energy decrease of 9 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 80 ft-lb for the weld HAZ metal.

A comparison, as presented in Table 5-10, of the Watts Bar Unit 1 reactor vessel surveillance material test results with the Regulatory Guide 1.99, Revision 2[1] predictions led to the following conclusions:

— The measured 30 ft-lb shift in transition temperature values of the intermediate shell forging 05 contained in capsule X (longitudinal & transverse) are less than the Regulatory Guide 1.99, Revision 2, predictions.

— The measured 30 ft-lb shift in transition temperature value of the weld metal contained in capsule X is less than the Regulatory Guide 1.99, Revision 2, predictions.

— The measured percent decrease in upper shelf energy for all the surveillance materials of Capsules X contained in the Watts Bar Unit 1 surveillance program are less than the Regulatory Guide 1.99, Revision 2 predictions.

The fracture appearance of each irradiated Charpy specimen from the various surveillance Capsule X materials is shown in Figures 5-13 through 5-16 and shows an increasingly ductile or tougher appearance with increasing test temperature.

The load-time records for individual instrumented Charpy specimen tests are shown in Appendix B.

The results presented in this report are a re-plot of all past capsule data and the new capsule X data based on using CVGRAPH, Version 5.0.2. Appendix C presents the individual CVGRAPH, Version 5.0.2, Charpy V-notch plots and the program input data.

All beltline materials, with exception to the intermediate shell forging 05, are expected to have an upper shelf energy (USE) greater than 50 ft-lb through end of license (EOL, 32 EFPY) as required by 10CFR50, Appendix G[2].

In September of 1993, Westinghouse completed an evaluation to demonstrate that all Westinghouse Owners Group (WOG) Plant reactor vessels have a margin of safety, relative to USE, equivalent to that required by Appendix G of the ASME Code. This was accomplished by performing generic bounding evaluations per the proposed ASME Section XI, Appendix X. This evaluation is documented in WCAP-13587, Revision 1[6], "Reactor Vessel Upper Shelf Energy Bounding Evaluation for Westinghouse Pressurized Water Reactors" and provides the minimum USE for a four loop Westinghouse NSSS plant. The minimum acceptable USE for a 4 loop plant is 43 ft-lb. The projected minimum EOL USE for the Watts Bar Unit 1 intermediate shell forging 05 is greater than 43 ft-lb. Hence, the bounding WOG evaluation shows that the Watts Bar Unit 1 intermediate shell forging 05 will maintain an equivalent margin, with respect to USE per the requirements of 10 CFR Part 50, Appendix G, through EOL (ie. Maintain this margin through EOL). In addition, the results of capsule X testing indicate that the measured EOL USE for the axially oriented Charpy specimens actually increased by approximately 4 ft-lb.

In addition, as part of the Capsule W testing, Framatome performed 1/2T compact tension tests to determine the upper shelf J-R curve for the intermediate shell forging 05. The purpose of this test was to demonstrate that the Watts Bar Unit 1 reactor vessel has margins of safety equivalent to the ASME Code Appendix G. The results were that the low upper shelf for intermediate shell forging 05 had sufficient margin. Lastly, as part of this capsule testing, Westinghouse will be performing a similar test and analysis, with the same purpose as that was previously performed by Framatome. This report will be published following the issuance of this report.

5.3 TENSILE TEST RESULTS

The results of the tensile tests performed on the various materials contained in Capsule X irradiated to 1.71×10^{19} n/cm^2 (E> 1.0 MeV) are presented in Table 5-11 and are compared with unirradiated results[4] as shown in Figures 5-17 and 5-19.

The results of the tensile tests performed on the Intermediate Shell Forging 05 (tangential orientation) indicated that irradiation to 1.71×10^{19} n/cm^2 (E> 1.0 MeV) caused approximately a 6 to 10 ksi increase in the 0.2 percent offset yield strength and approximately a 6 to 10 ksi increase in the ultimate tensile strength when compared to unirradiated data[4]. See Figure 5-17.

The results of the tensile tests performed on the Intermediate Shell Forging 05 (axial orientation) indicated that irradiation to 1.71×10^{19} n/cm^2 (E> 1.0 MeV) caused approximately a 8 to 12 ksi increase in the 0.2 percent offset yield strength and approximately a 9 to 12 ksi increase in the ultimate tensile strength when compared to unirradiated data[4]. See Figure 5-18.

The results of the tensile tests performed on the surveillance weld metal indicated that irradiation to 1.71×10^{19} n/cm^2 (E> 1.0 MeV) caused approximately a 5 to 9 ksi increase in the 0.2 percent offset yield strength and approximately a 4 to 6 ksi increase in the ultimate tensile strength when compared to unirradiated data[4]. See Figure 5-19.

The fractured tensile specimens for the Intermediate Shell Forging 05 material are shown in Figures 5-20 and 5-21, while the fractured tensile specimens for the surveillance weld metal are shown in Figure 5-22. The engineering stress-strain curves for the tensile tests are shown in Figures 5-23 through 5-25.

5.4 1/2T COMPACT TENSION SPECIMEN TESTS

Per the surveillance capsule testing contract, the 1/2T Compact Tension Specimens are to be tested. The test results and corresponding evaluations will be presented in a separate report published after the issuance of this report.

Table 5-1 Charpy V-notch Data for the Watts Bar Unit 1 Intermediate Shell Forging 05 Irradiated to a Fluence of 1.71 x 10^{19} n/cm^2 (E> 1.0 MeV) (Tangential Orientation)							
Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	°F	°C	ft-lbs	Joules	mils	mm	%
WL55	-75	-59	10	14	4	0.10	2
WL60	-50	-46	8	11	0	0.00	2
WL54	-25	-32	22	30	14	0.36	5
WL50	0	-18	25	34	13	0.33	5
WL47	25	-4	22	30	11	0.28	10
WL52	40	4	29	39	16	0.41	10
WL57	50	10	42	57	25	0.64	20
WL51	75	24	31	42	19	0.48	20
WL58	100	38	63	85	40	1.02	40
WL53	125	52	64	87	44	1.12	60
WL56	160	71	75	102	48	1.22	75
WL59	180	82	79	107	51	1.30	75
WL49	225	107	107	145	72	1.83	100
WL46	250	121	101	137	69	1.75	100
WL48	250	121	111	151	71	1.80	100

Table 5-2 Charpy V-notch Data for the Watts Bar Unit 1 Intermediate Shell Forging 05 Irradiated to a Fluence of 1.71 x 10^{19} n/cm^2 (E> 1.0 MeV) (Axial Orientation)							
Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	°F	°C	ft-lbs	Joules	mils	mm	%
WT60	0	-18	4	5	0	0.00	2
WT47	50	10	12	16	7	0.18	5
WT57	100	38	13	18	13	0.33	15
WT54	125	52	28	38	22	0.56	20
WT49	125	52	16	22	14	0.36	20
WT56	150	66	27	37	24	0.61	25
WT58	175	79	30	41	26	0.66	40
WT59	200	93	36	49	30	0.76	40
WT46	210	99	38	52	33	0.84	60
WT50	225	107	52	71	44	1.12	80
WT51	250	121	66	89	50	1.27	100
WT53	250	121	64	87	52	1.32	100
WT48	275	135	73	99	53	1.35	100
WT52	275	135	63	85	49	1.24	100
WT55	300	149	64	87	55	1.40	100

Table 5-3 Charpy V-notch Data for the Watts Bar Unit 1 Surveillance Weld Metal Irradiated to a Fluence of 1.71 x 10^{19} n/cm^2 (E> 1.0 MeV)							
Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	°F	°C	ft-lbs	Joules	mils	mm	%
WW55	-100	-73	5	7	1	0.03	10
WW47	-75	-59	14	19	9	0.23	15
WW46	-50	-46	23	31	13	0.33	15
WW48	-25	-32	21	28	14	0.36	25
WW52	10	-12	51	69	37	0.94	20
WW59	25	-4	26	35	18	0.46	30
WW57	50	10	49	66	37	0.94	25
WW49	75	24	91	123	60	1.52	65
WW53	100	38	78	106	55	1.40	60
WW50	125	52	94	127	68	1.73	75
WW60	175	79	100	136	71	1.80	70
WW56	200	93	125	170	85	2.16	100
WW58	225	107	138	187	78	1.98	95
WW54	225	107	130	176	80	2.03	100
WW51	275	135	143	194	86	2.18	100

Table 5-4 Charpy V-notch Data for the Watts Bar Unit 1 Heat-Affected-Zone (HAZ) Material Irradiated to a Fluence of 1.71×10^{19} n/cm^2 (E> 1.0 MeV)

Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	°F	°C	Ft-lbs	Joules	mils	mm	%
WH54	-75	-59	8	11	0	0.00	5
WH51	-50	-46	16	22	4	0.10	10
WH50	0	-18	22	30	10	0.25	25
WH56	25	-4	29	39	18	0.46	30
WH46	50	10	42	57	29	0.74	50
WH47	75	24	59	80	36	0.91	45
WH55	100	38	75	102	54	1.37	90
WH49	125	52	58	79	34	0.86	70
WH52	150	66	58	79	42	1.07	60
WH48	200	93	87	118	66	1.68	95
WH58	200	93	97	132	58	1.47	90
WH53	225	107	96	130	70	1.78	90
WH59	250	121	92	125	65	1.65	100
WH60	275	135	69	94	41	1.04	100
WH57	300	149	79	107	47	1.19	100

Table 5-5 Instrumented Charpy Impact Test Results for the Watts Bar Unit 1 Intermediate Shell Forging 05 Irradiated to a Fluence of 1.71×10^{19} n/cm^2 (E>1.0 MeV) (Tangential Orientation)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2) Charpy E_D/A	Max. E_M/A	Prop. E_P/A	Yield Load P_{GY} (lb)	Time to Yield t_{GY} (msec)	Max. Load P_M (lb)	Time to Max. t_M (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress σ_Y (ksi)	Flow Stress (ksi)
WL55	-75	10	81	51	30	4490	0.16	4695	0.18	4695	0	150	153
WL60	-50	8	64	37	27	3835	0.15	3907	0.16	3907	0	128	129
WL54	-25	22	177	84	93	4410	0.18	4878	0.24	4770	0	147	155
WL50	0	25	201	74	127	3993	0.15	4791	0.22	4778	0	133	146
WL47	25	22	177	70	107	3760	0.14	4576	0.21	4528	0	125	139
WL52	40	29	234	191	43	3817	0.14	4839	0.41	4837	0	127	144
WL57	50	42	338	260	79	3905	0.15	4969	0.52	4912	0	130	148
WL51	75	31	250	192	58	3762	0.14	4904	0.41	4901	0	125	144
WL58	100	63	508	341	166	3671	0.14	4830	0.67	4504	0	122	142
WL53	125	64	516	254	262	3672	0.14	4818	0.52	4466	683	122	141
WL56	160	75	604	281	323	3104	0.17	4737	0.62	4453	1395	103	131
WL59	180	79	637	322	314	3424	0.14	4575	0.67	3815	1441	114	133
WL49	225	107	862	246	616	3246	0.14	4779	0.53	n/a	n/a	108	134
WL46	250	101	814	328	486	3472	0.14	4699	0.67	n/a	n/a	116	136
WL48	250	111	894	323	571	3336	0.15	4661	0.67	n/a	n/a	111	133

Table 5-6 Instrumented Charpy Impact Test Results for the Watts Bar Unit 1 Intermediate Shell Forging 05 Irradiated to a Fluence of 1.71 x 10^{19} n/cm^2 (E>1.0 MeV) (Axial Orientation)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2)			Yield Load P_{GY} (lb)	Time to Yield t_{GY} (msec)	Max. Load P_M (lb)	Time to Max. t_M (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress σ_Y (ksi)	Flow Stress (ksi)
			Charpy E_D/A	Max. E_M/A	Prop. E_p/A								
WT60	0	4	32	17	15	2098	0.11	2143	0.12	2143	0	70	71
WT47	50	12	97	52	44	3627	0.15	4173	0.19	4159	0	121	130
WT57	100	13	105	38	66	3406	0.15	3637	0.17	3637	624	113	117
WT54	125	28	226	150	75	3274	0.13	4212	0.37	4203	490	109	125
WT49	125	16	129	51	78	3387	0.14	3905	0.19	3897	579	113	121
WT56	150	27	218	66	152	3222	0.13	4045	0.22	3893	1224	107	121
WT58	175	30	242	62	180	3155	0.14	3957	0.21	3854	1967	105	118
WT59	200	36	290	158	132	3061	0.13	4106	0.40	4082	1707	102	119
WT46	210	38	306	158	149	3071	0.13	4047	0.40	4009	1665	102	119
WT50	225	52	419	190	229	3138	0.14	4083	0.47	3799	2306	104	120
WT51	250	66	532	217	315	3161	0.14	4240	0.51	n/a	n/a	105	123
WT53	250	64	516	201	315	3104	0.14	4119	0.49	n/a	n/a	103	120
WT48	275	73	588	215	373	3181	0.14	4321	0.50	n/a	n/a	106	125
WT52	275	63	508	171	336	3101	0.14	4154	0.43	n/a	n/a	103	121
WT55	300	64	516	203	313	2986	0.14	4082	0.50	n/a	n/a	99	118

Table 5-7 Instrumented Charpy Impact Test Results for the Watts Bar Unit 1 Surveillance Weld Metal Irradiated to a Fluence of 1.71 x 10^{19} n/cm^2 (E>1.0 MeV)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2) Charpy E_D/A	Max. E_M/A	Prop. E_P/A	Yield Load P_{GY} (lb)	Time to Yield t_{GY} (msec)	Max. Load P_M (lb)	Time to Max. t_M (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress σ_Y (ksi)	Flow Stress (ksi)
WW55	-100	5	40	19	21	2374	0.12	2407	0.13	2399	0	79	80
WW47	-75	14	113	48	65	3882	0.17	4049	0.19	4028	492	129	132
WW46	-50	23	185	63	122	3744	0.15	4385	0.21	4283	0	125	135
WW48	-25	21	169	60	109	3298	0.14	4067	0.21	4024	1667	110	123
WW52	10	51	411	321	90	3460	0.14	4499	0.67	4370	220	115	133
WW59	25	26	209	48	161	3488	0.14	3956	0.18	3953	2364	116	124
WW57	50	49	395	294	100	3405	0.14	4472	0.63	4464	1433	113	131
WW49	75	91	733	328	406	3383	0.14	4570	0.69	3724	1488	113	132
WW53	100	78	628	314	314	3188	0.14	4422	0.68	4050	1381	106	127
WW50	125	94	757	308	449	3243	0.15	4309	0.69	3316	1155	108	126
WW60	175	100	806	313	493	3261	0.15	4356	0.69	2300	753	109	127
WW56	200	125	1007	296	711	3032	0.14	4235	0.68	n/a	n/a	101	121
WW58	225	138	1112	313	799	3265	0.14	4425	0.68	2643	1829	109	128
WW54	225	130	1047	301	747	3028	0.14	4188	0.69	n/a	n/a	101	120
WW51	275	143	1152	300	853	3098	0.14	4272	0.67	n/a	n/a	103	123

Table 5-8 Instrumented Charpy Impact Test Results for the Watts Bar Unit 1 Heat-Affected-Zone (HAZ) Metal Irradiated to a Fluence of 1.71 x 10^{19} n/cm^2 (E>1.0 MeV)													
Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in²)			Yield Load P_{GY} (lb)	Time to Yield t_{GY} (msec)	Max. Load P_M (lb)	Time to Max. t_M (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress σ_Y (ksi)	Flow Stress (ksi)
			Charpy E_D/A	Max. E_M/A	Prop. E_p/A								
WH54	-75	8	64	39	25	3922	0.14	4181	0.16	4181	0	131	135
WH51	-50	16	129	74	55	4162	0.15	4969	0.21	4969	0	139	152
WH50	0	22	177	66	112	3957	0.15	4653	0.20	4650	1484	132	143
WH56	25	29	234	67	166	3850	0.14	4588	0.21	4558	892	128	140
WH46	50	42	338	69	269	3781	0.14	4630	0.21	4388	965	126	140
WH47	75	59	475	196	279	3720	0.14	4707	0.42	4586	1922	124	140
WH55	100	75	604	223	381	3599	0.14	4507	0.49	660	251	120	135
WH49	125	58	467	218	250	3525	0.14	4592	0.47	4481	2645	117	135
WH52	150	58	467	162	305	3318	0.13	4270	0.38	3851	3172	110	126
WH48	200	87	701	234	467	3462	0.14	4389	0.52	3838	3051	115	131
WH58	200	97	782	318	464	3320	0.14	4473	0.67	3141	2639	111	130
WH53	225	96	774	237	537	3462	0.14	4564	0.52	3922	2376	115	134
WH59	250	92	741	218	523	3345	0.14	4448	0.49	n/a	n/a	111	130
WH60	275	69	556	200	356	3274	0.14	4299	0.47	n/a	n/a	109	126
WH57	300	79	637	284	352	3119	0.16	4417	0.64	n/a	n/a	104	125

Table 5-9 Effect of Irradiation to 1.71 x 10^{19} n/cm^2 (E>1.0 MeV) on the Capsule V Notch Toughness Properties of the Watts Bar Unit 1 Reactor Vessel Surveillance Materials

Material	Average 30 (ft-lb)[a] Transition Temperature (°F)			Average 35 mil Lateral[b] Expansion Temperature (°F)			Average 50 ft-lb[a] Transition Temperature (°F)			Average Energy Absorption[a] at Full Shear (ft-lb)		
	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔE
Intermediate Shell Forging 05 (Tang.)	-57.1	37.6	94.7	-9.4	106.6	116.0	-15.4	87.2	102.6	132	106	-26
Intermediate Shell Forging 05 (Axial)	45.2	161.1	115.9	84.6	201.6	117.0	114.2	218.3	104.1	62	66	+4
Weld Metal (Heat # 895075)	-31.2	-5.4	25.8	-9.9	35.9	45.8	-5.9	37.9	43.8	131	134	+3
HAZ Metal	-56.2	18.6	74.8	-0.6	72.6	73.2	-8.6	62.5	71.1	89	80	-9

a. "Average" is defined as the value read from the curve fit through the data points of the Charpy tests (see Figures 5-1, 5-4, 5-7 and 5-10).

b. "Average" is defined as the value read from the curve fit through the data points of the Charpy tests (see Figures 5-2, 5-5, 5-8 and 5-11).

Table 5-10 Comparison of the Watts Bar Unit 1 Surveillance Material 30 ft-lb Transition Temperature Shifts and Upper Shelf Energy Decreases with Regulatory Guide 1.99, Revision 2, Predictions

Material	Capsule	Fluence[d] ($x 10^{19}$ n/cm^2, E > 1.0 MeV)	30 ft-lb Transition Temperature Shift		Upper Shelf Energy Decrease	
			Predicted (°F)[a]	Measured (°F)[b]	Predicted (%)[a]	Measured (%)[c]
Intermediate Shell	U	0.447	95.4	98.3	21	19
Forging 05	W	1.08	125.5	111.4	26	26
(Tangential)	X	1.71	141.5	94.7	29	20
Intermediate Shell	U	0.447	95.4	28.7	21	0
Forging 05	W	1.08	125.5	79.0	26	3
(Axial)	X	1.71	141.5	115.9	29	0
Surveillance	U	0.447	31.8	0.0[e]	16	0
Program	W	1.08	41.8	30.5	19	15
Weld Metal	X	1.71	47.2	25.8	22	0
Heat Affected Zone	U	0.447	---	50.9	---	11
Material	W	1.08	---	48.8	---	13
	X	1.71	---	74.8	---	10

Notes:

(a) Based on Regulatory Guide 1.99, Revision 2, methodology using the mean weight percent values of copper and nickel of the surveillance material.

(b) Calculated using measured Charpy data plotted using CVGRAPH, Version 4.1 (See Appendix C)

(c) Values are based on the definition of upper shelf energy given in ASTM E185-82.

(d) The fluence values presented here are the "calculated" values.

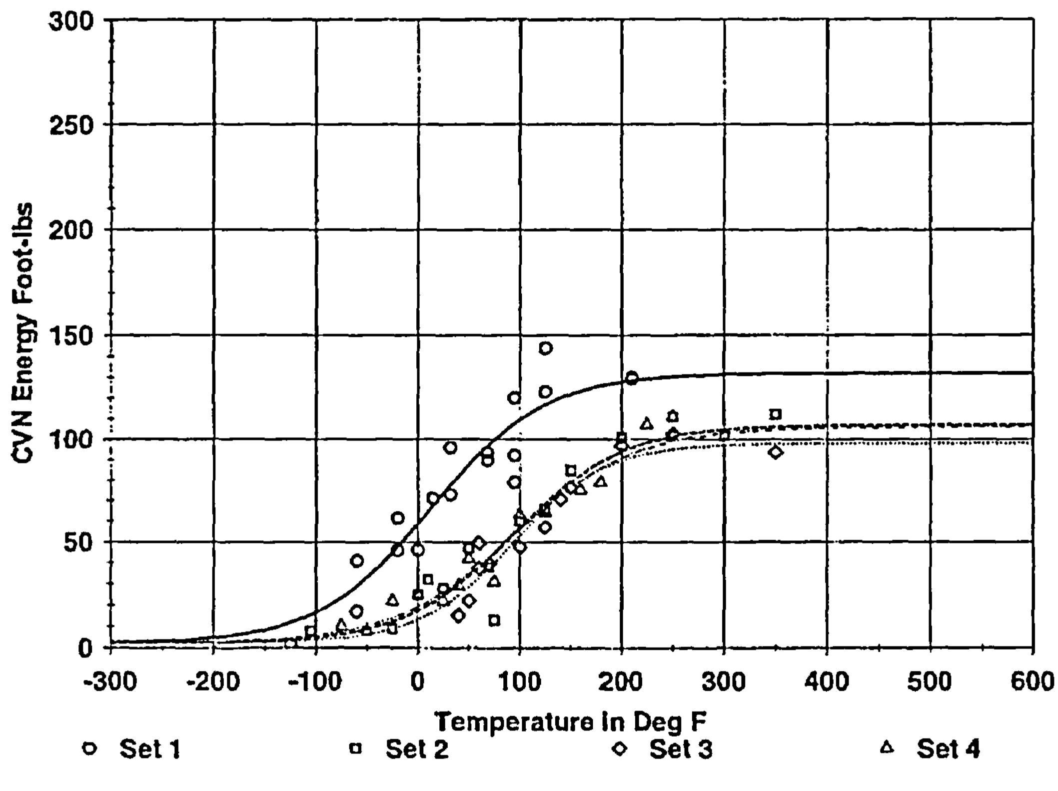
(e) Due to the scatter in the Capsule U Weld Charpy test results, a true Hyperbolic Tangent Curve fit resulted in ΔT_{30} values of −6.4°F when compared to unirradiated Charpy test data. Physically this should not happen. Hence, based on engineering judgement a value of 0°F will be used in RT_{NDT} calculations.

Table 5-11 Tensile Properties of the Watts Bar Unit 1 Capsule X Reactor Vessel Surveillance Materials Irradiated to 1.71 x 10^{19} n/cm^2 (E > 1.0 MeV)										
Material	Sample Number	Test Temp. (°F)	0.2% Yield Strength (ksi)	Ultimate Strength (ksi)	Fracture Load (kip)	Fracture Stress (ksi)	Fracture Strength (ksi)	Uniform Elongation (%)	Total Elongation (%)	Reduction In Area (%)
Intermediate Shell Forging 05 (Tangential)	WL-10	75	86.6	106.3	3.61	200.0	73.5	10.5	23.3	63
	WL-11	300	78.9	98.7	3.30	150.7	67.2	9.0	20.3	55
	WL-12	550	76.5	100.2	3.45	185.4	70.2	10.5	21.8	62
Intermediate Shell Forging 05 (Axial)	WT-10	75	86.8	106.5	4.12	187.9	83.8	11.3	21.8	55
	WT-11	300	77.6	99.0	3.90	156.7	79.5	9.8	17.9	49
	WT-12	550	78.2	100.0	4.11	157.3	83.7	9.0	16.4	47
Weld Metal	WW-10	75	77.8	89.8	2.55	199.3	51.8	13.5	30.8	74
	WW-11	300	70.8	81.7	2.37	173.1	48.2	11.3	26.3	72
	WW-12	550	68.6	84.0	2.57	175.8	52.3	10.5	23.4	70

INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/06/2004 11:20 AM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Watts Bar 1	UNIRR	SA508CL2	LT	527536
2	Watts Bar 1	U	SA508CL2	LT	527536
3	Watts Bar 1	W	SA508CL2	LT	527536
4	Watts Bar 1	X	SA508CL2	LT	527536



Results

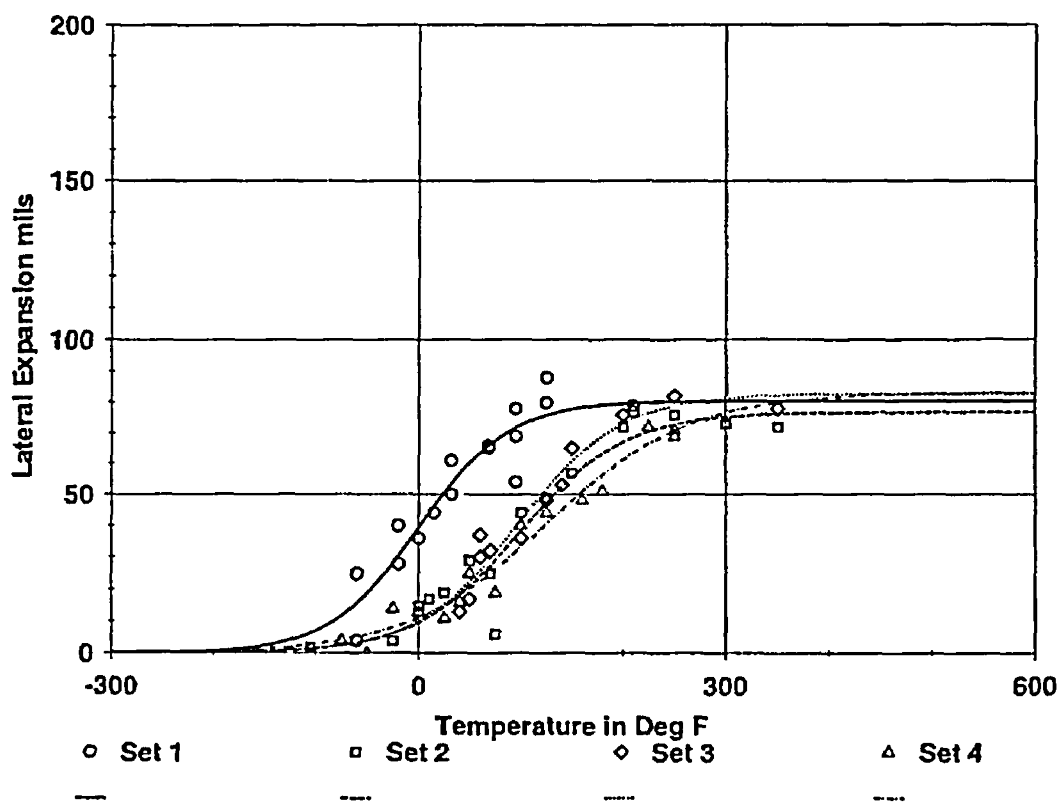
Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1	0.0	2.2	132.0	.0	-57.1	.0	-15.4	.0
2	0.0	2.2	107.0	-25.0	41.2	98.3	86.4	101.8
3		2.2	98.0	-34.0	54.3	111.4	95.0	110.4
4		2.2	106.0	-26.0	37.6	94.7	87.2	102.6

Figure 5-1 Charpy V-Notch Impact Energy vs. Temperature for Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Tangential Orientation)

INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/06/2004 02:09 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Watts Bar 1	UNIRR	SA508CL2	LT	527536
2	Watts Bar 1	U	SA508CL2	LT	527536
3	Watts Bar 1	W	SA508CL2	LT	527536
4	Watts Bar 1	X	SA508CL2	LT	527536



Results

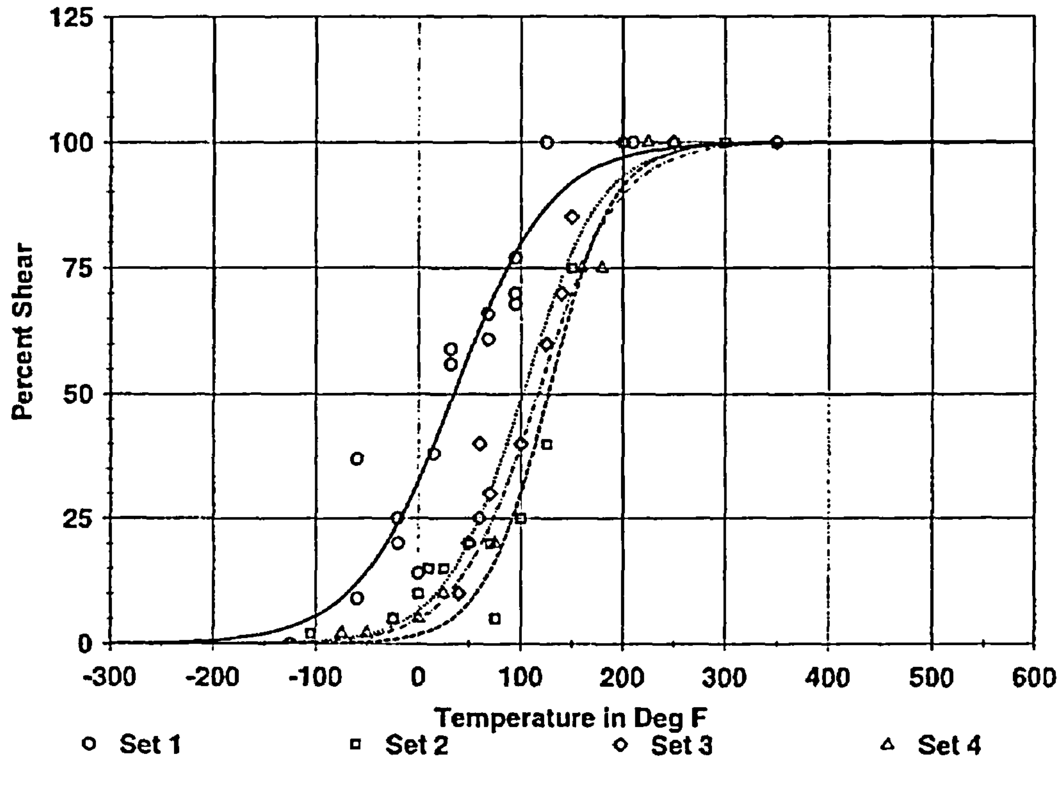
Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1	0.0	.0	80.5	.0	-9.4	.0
2	0.0	.0	76.9	-3.6	91.0	100.4
3		.0	82.6	2.1	84.3	93.7
4		.0	83.1	2.6	106.6	116.0

Figure 5-2 Charpy V-Notch Lateral Expansion vs. Temperature for Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Tangential Orientation)

INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/06/2004 02:01 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Watts Bar 1	UNIRR	SA508CL2	LT	527536
2	Watts Bar 1	U	SA508CL2	LT	527536
3	Watts Bar 1	W	SA508CL2	LT	527536
4	Watts Bar 1	X	SA508CL2	LT	527536



Results

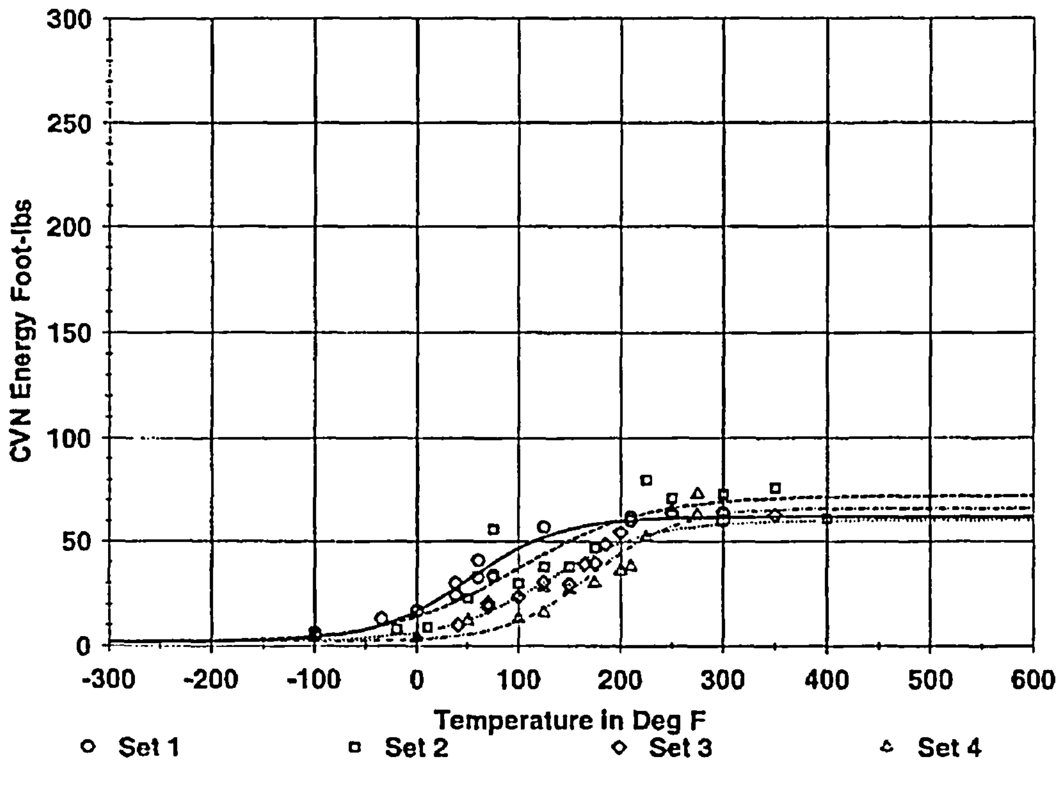
Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1	0.0	.0	100.0	.0	34.8	.0
2	0.0	.0	100.0	.0	126.6	91.8
3		.0	100.0	.0	102.3	67.5
4		.0	100.0	.0	116.6	81.8

Figure 5-3 Charpy V-Notch Percent Shear vs. Temperature for Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Tangential Orientation)

INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 09:59 AM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Watts Bar 1	UNIRR	SA508CL2	TL	527536
2	Watts Bar 1	U	SA508CL2	TL	527536
3	Watts Bar 1	W	SA508CL2	TL	527536
4	Watts Bar 1	X	SA508CL2	TL	527536



Results

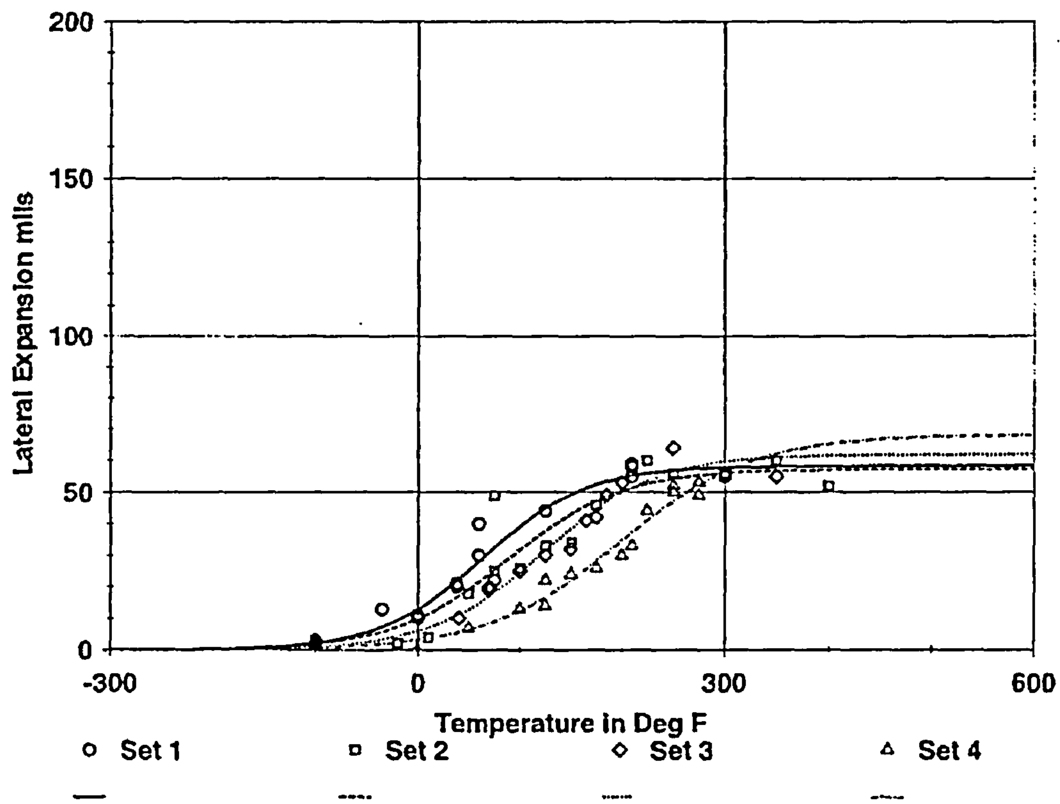
Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1	0.0	2.2	62.0	.0	45.2	.0	114.2	.0
2	0.0	2.2	72.0	10.0	73.9	28.7	148.7	34.5
3		2.2	60.0	-2.0	124.2	79.0	206.2	92.0
4		2.2	66.0	4.0	161.1	115.9	218.3	104.1

Figure 5-4 Charpy V-Notch Impact Energy vs. Temperature for Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Axial Orientation)

INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 10:45 AM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Watts Bar 1	UNIRR	SA508CL2	TL	527536
2	Watts Bar 1	U	SA508CL2	TL	527536
3	Watts Bar 1	W	SA508CL2	TL	527536
4	Watts Bar 1	X	SA508CL2	TL	527536



Results

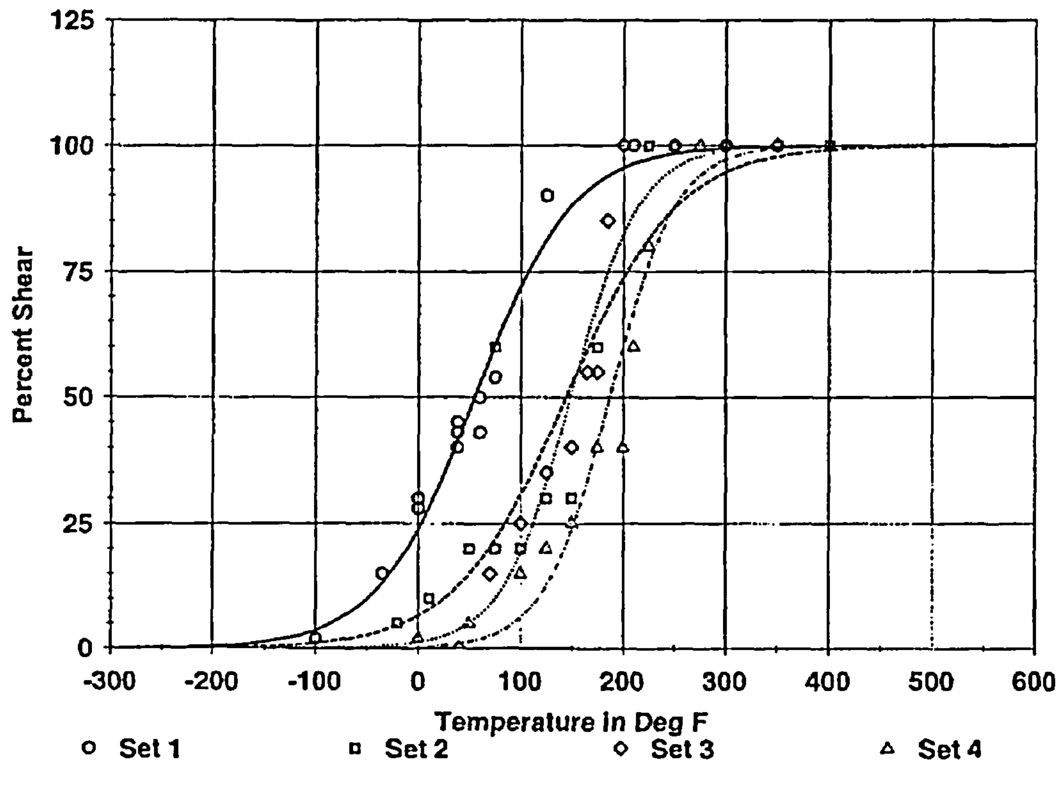
Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		.0	58.3	.0	84.6	.0
2		.0	57.3	-1.0	113.4	28.8
3		.0	61.8	3.5	138.1	53.5
4		.0	68.1	9.8	201.6	117.0

Figure 5-5 Charpy V-Notch Lateral Expansion vs. Temperature for Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Axial Orientation)

INTERMEDIATE SHELL 05

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 10:29 AM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Watts Bar 1	UNIRR	SA508CL2	TL	527536
2	Watts Bar 1	U	SA508CL2	TL	527536
3	Watts Bar 1	W	SA508CL2	TL	527536
4	Watts Bar 1	X	SA508CL2	TL	527536



Results

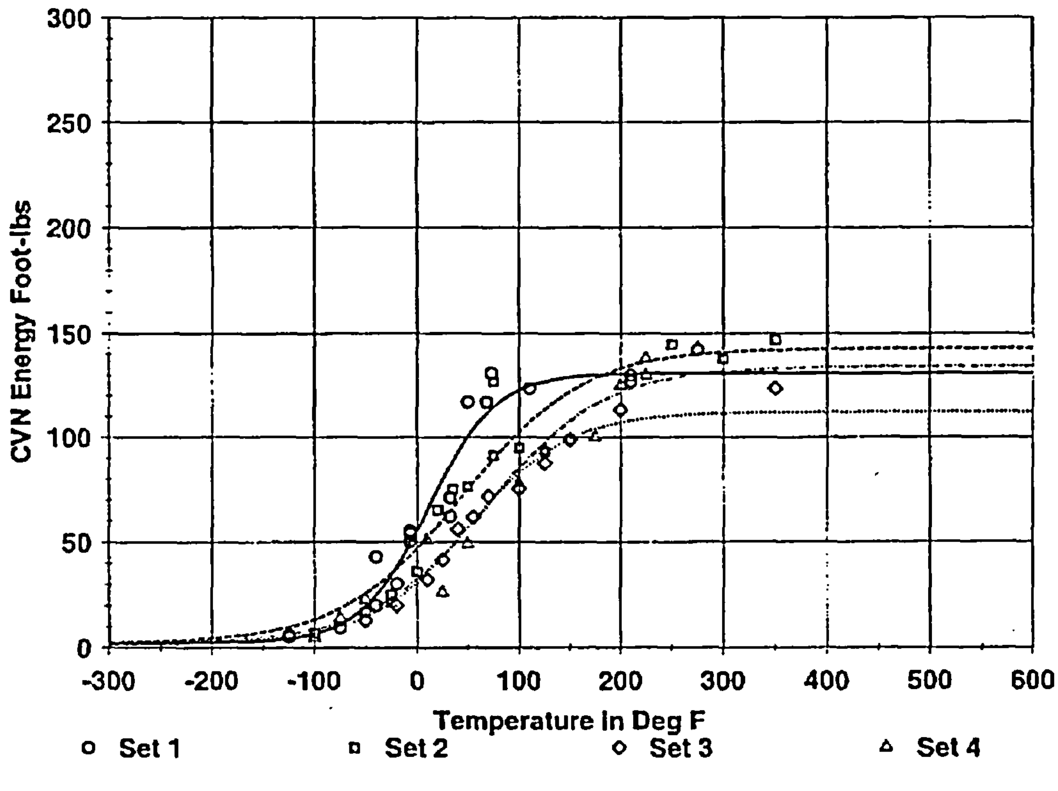
Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	54.9	.0
2		.0	100.0	.0	144.3	89.4
3		.0	100.0	.0	149.1	94.2
4		.0	100.0	.0	187.3	132.4

Figure 5-6 Charpy V-Notch Percent Shear vs. Temperature for Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Axial Orientation)

SURVIELLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 01:41 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Watts Bar 1	UNIRR	N/A	NA	895075 FLUX
2	Watts Bar 1	U	N/A	NA	895075
3	Watts Bar 1	W	N/A	NA	895075
4	Watts Bar 1	X	N/A	NA	895075



Results

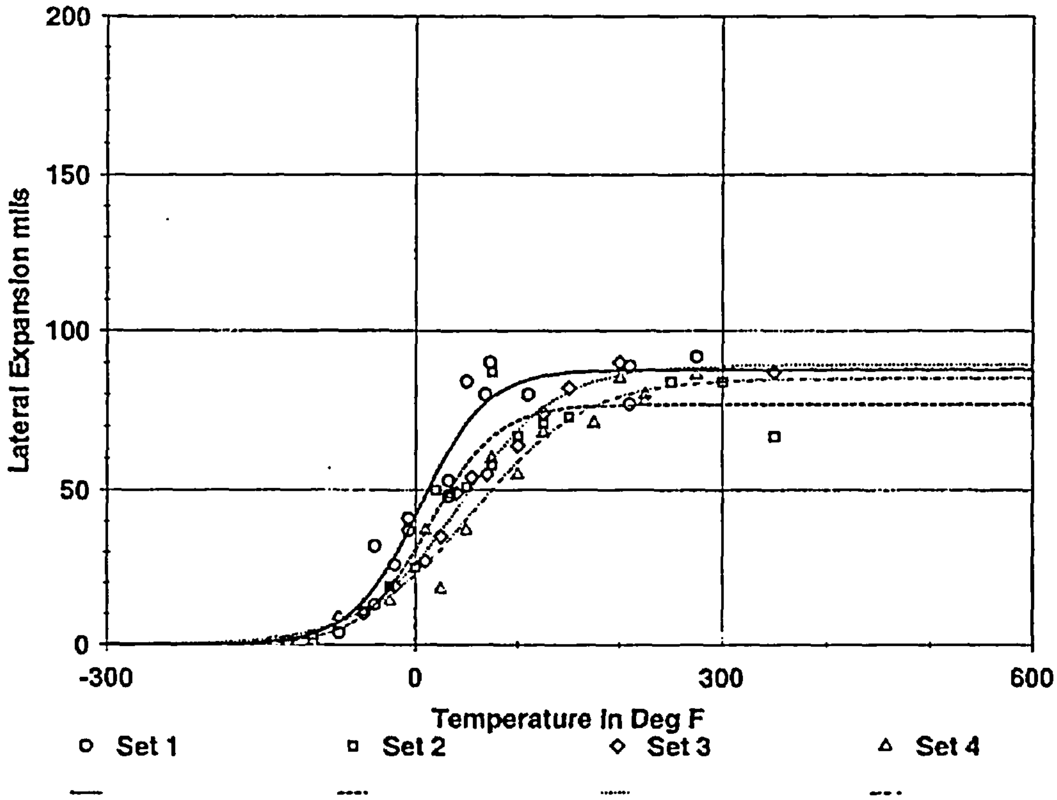
Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	131.0	.0	-31.2	.0	-5.9	.0
2		2.2	143.0	12.0	-37.6	-6.4	6.3	12.2
3		2.2	112.0	-19.0	-.7	30.5	39.4	45.3
4		2.2	134.0	3.0	-5.4	25.8	37.9	43.8

Figure 5-7 Charpy V-Notch Impact Energy vs. Temperature for Watts Bar Unit 1 Reactor Vessel Weld Metal

SURVIELLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 02:11 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Watts Bar 1	UNIRR	N/A	NA	895075 FLUX
2	Watts Bar 1	U	N/A	NA	895075
3	Watts Bar 1	W	N/A	NA	895075
4	Watts Bar 1	X	N/A	NA	895075



Results

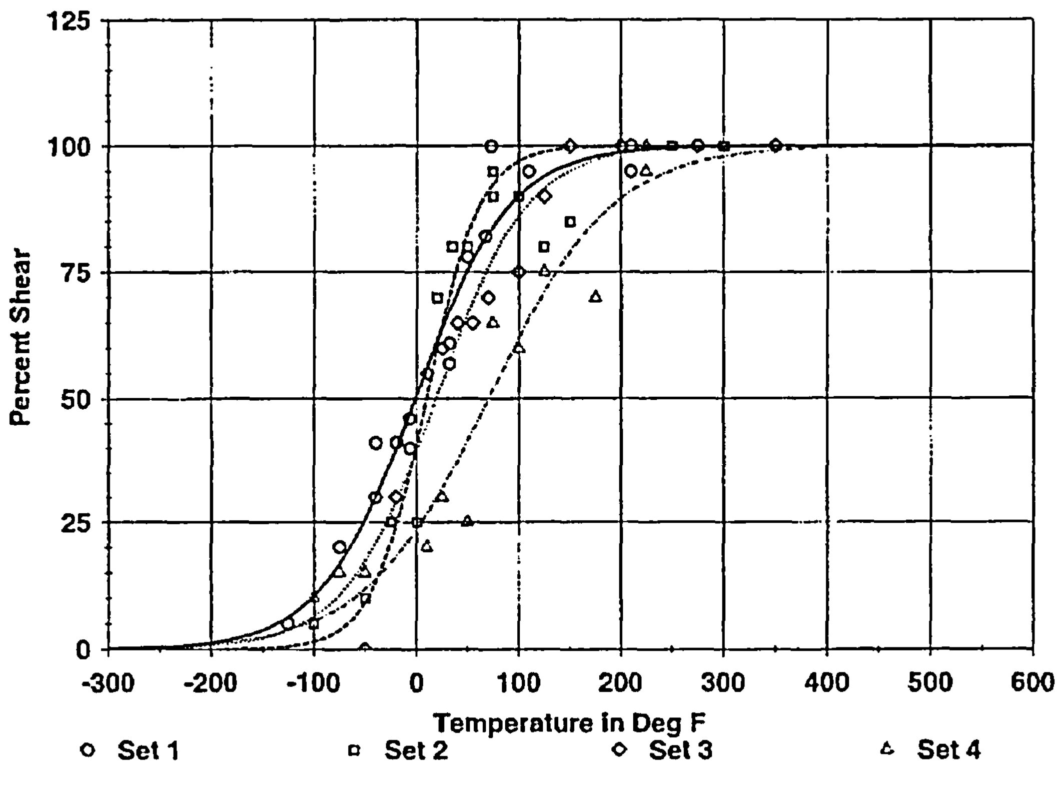
Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		.0	87.8	.0	-9.9	.0
2		.0	76.9	-10.9	7.4	17.3
3		.0	89.2	1.4	21.9	31.8
4		.0	85.0	-2.8	35.9	45.8

Figure 5-8 Charpy V-Notch Lateral Expansion vs. Temperature for Watts Bar Unit 1 Reactor Vessel Weld Metal

SURVIELLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 02:00 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Watts Bar 1	UNIRR	N/A	NA	895075 FLUX
2	Watts Bar 1	U	N/A	NA	895075
3	Watts Bar 1	W	N/A	NA	895075
4	Watts Bar 1	X	N/A	NA	895075



Results

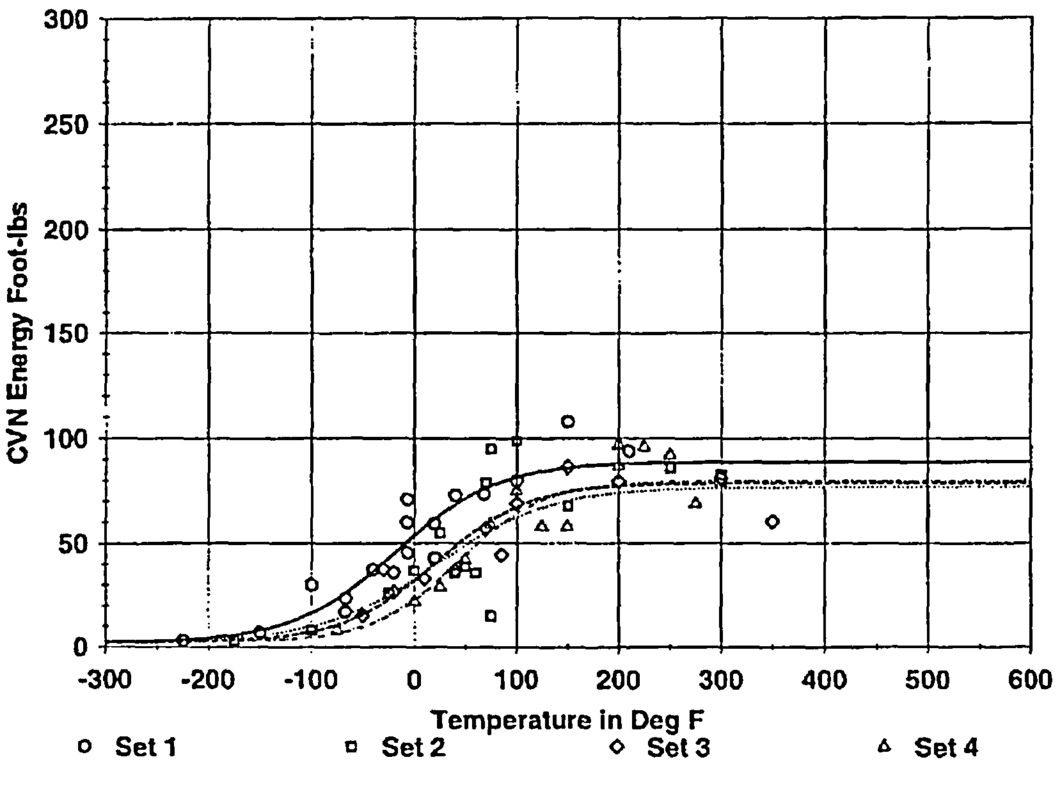
Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	-1.2	.0
2		.0	100.0	.0	9.6	10.8
3		.0	100.0	.0	19.9	21.1
4		.0	100.0	.0	70.9	72.1

Figure 5-9 Charpy V-Notch Percent Shear vs. Temperature for Watts Bar Unit 1 Reactor Vessel Weld Metal

HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 03:26 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Watts Bar 1	UNIRR	SA508CL2	NA	527536
2	Watts Bar 1	U	SA508CL2	NA	527536
3	Watts Bar 1	W	SA508CL2	NA	527536
4	Watts Bar 1	X	SA508CL2	NA	527536



Results

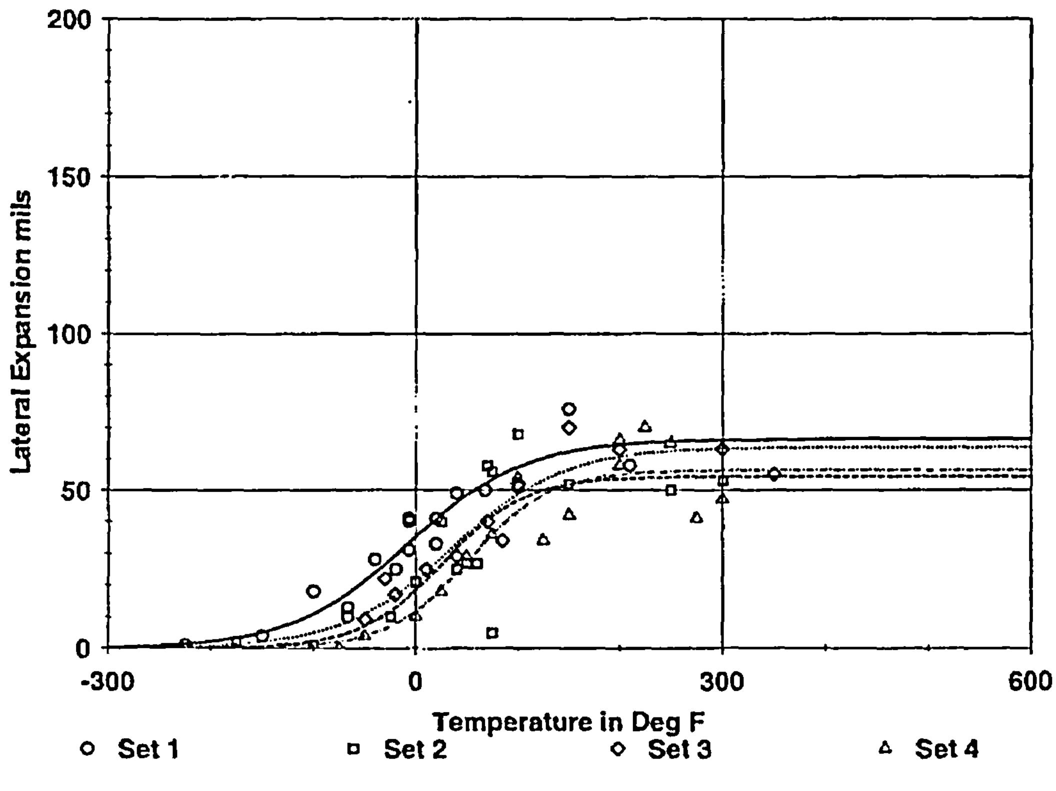
Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	89.0	.0	-56.2	.0	-8.6	.0
2		2.2	79.0	-10.0	-5.3	50.9	43.7	52.3
3		2.2	77.0	-12.0	-7.4	48.8	53.6	62.2
4		2.2	80.0	-9.0	18.6	74.8	62.5	71.1

Figure 5-10 Charpy V-Notch Impact Energy vs. Temperature for Watts Bar Unit 1 Reactor Vessel Heat-Affected-Zone Material

HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 03:41 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Watts Bar 1	UNIRR	SA508CL2	NA	527536
2	Watts Bar 1	U	SA508CL2	NA	527536
3	Watts Bar 1	W	SA508CL2	NA	527536
4	Watts Bar 1	X	SA508CL2	NA	527536



Results

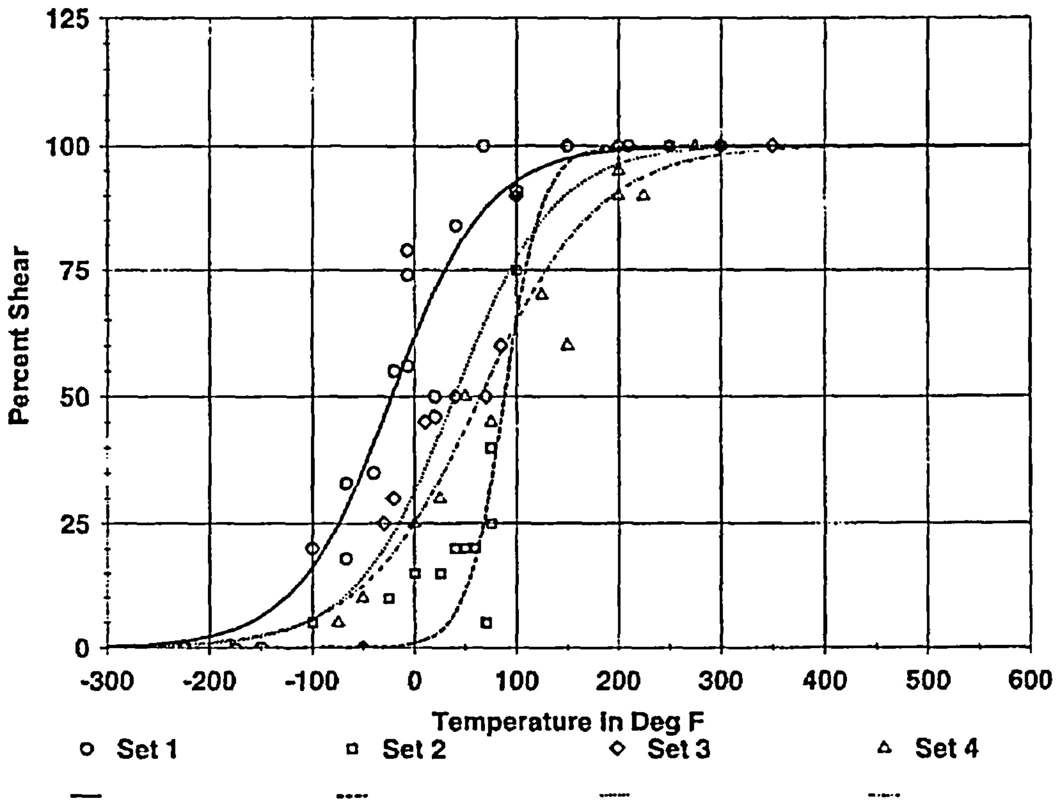
Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		.0	66.3	.0	-.6	.0
2		.0	54.4	-11.9	51.2	51.8
3		.0	63.6	-2.7	48.0	48.6
4		.0	56.3	-10.0	72.6	73.2

Figure 5-11 Charpy V-Notch Lateral Expansion vs. Temperature for Watts Bar Unit 1 Reactor Vessel Heat-Affected-Zone Material

HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 03:34 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Watts Bar 1	UNIRR	SA508CL2	NA	527536
2	Watts Bar 1	U	SA508CL2	NA	527536
3	Watts Bar 1	W	SA508CL2	NA	527536
4	Watts Bar 1	X	SA508CL2	NA	527536



Results

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	-22.2	.0
2		.0	100.0	.0	88.1	110.3
3		.0	100.0	.0	39.6	61.8
4		.0	100.0	.0	64.7	86.9

Figure 5-12 Charpy V-Notch Percent Shear vs. Temperature for Watts Bar Unit 1 Reactor Vessel Heat-Affected-Zone Material

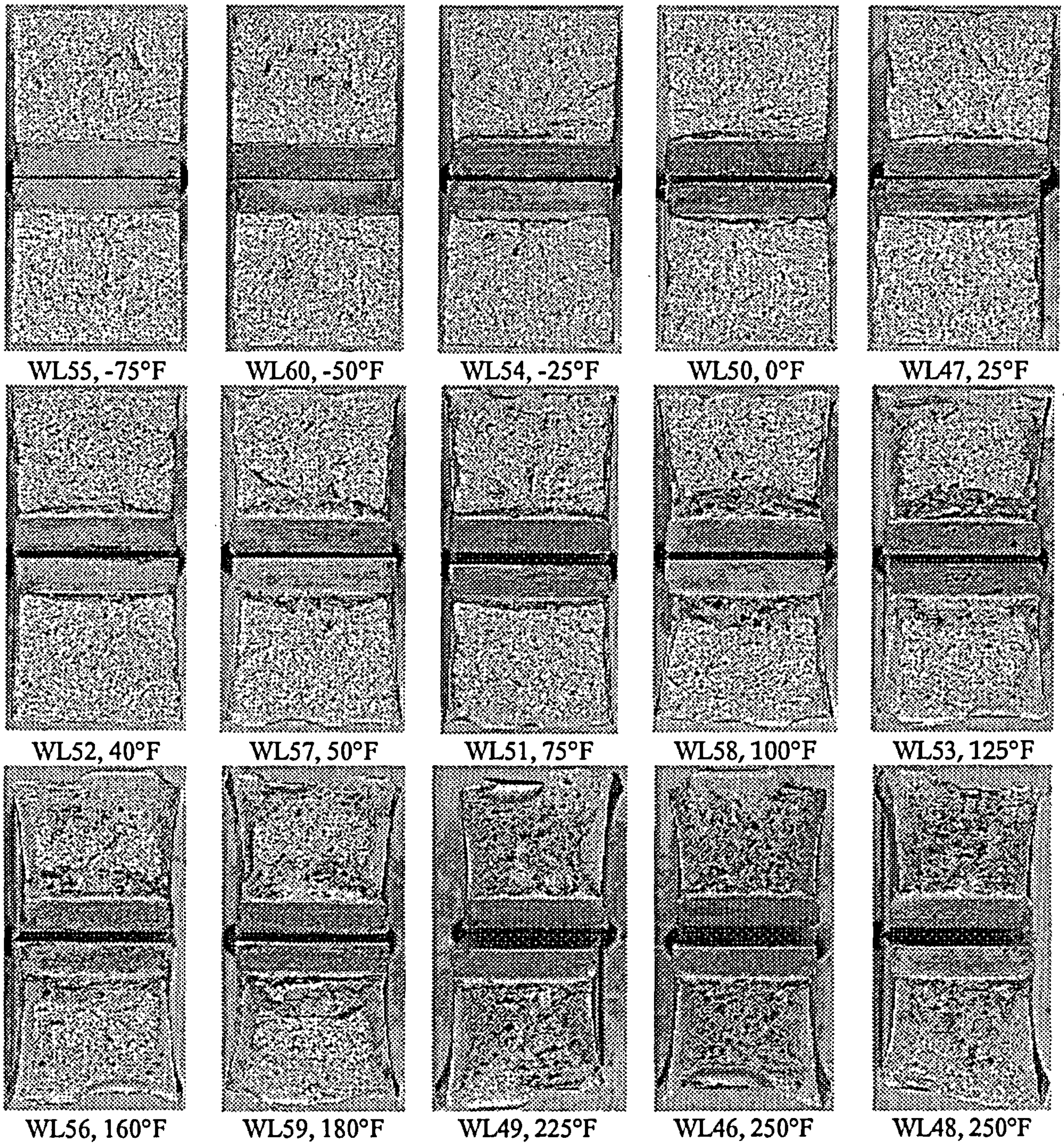


Figure 5-13 Charpy Impact Specimen Fracture Surfaces for Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging (Tangential Orientation)

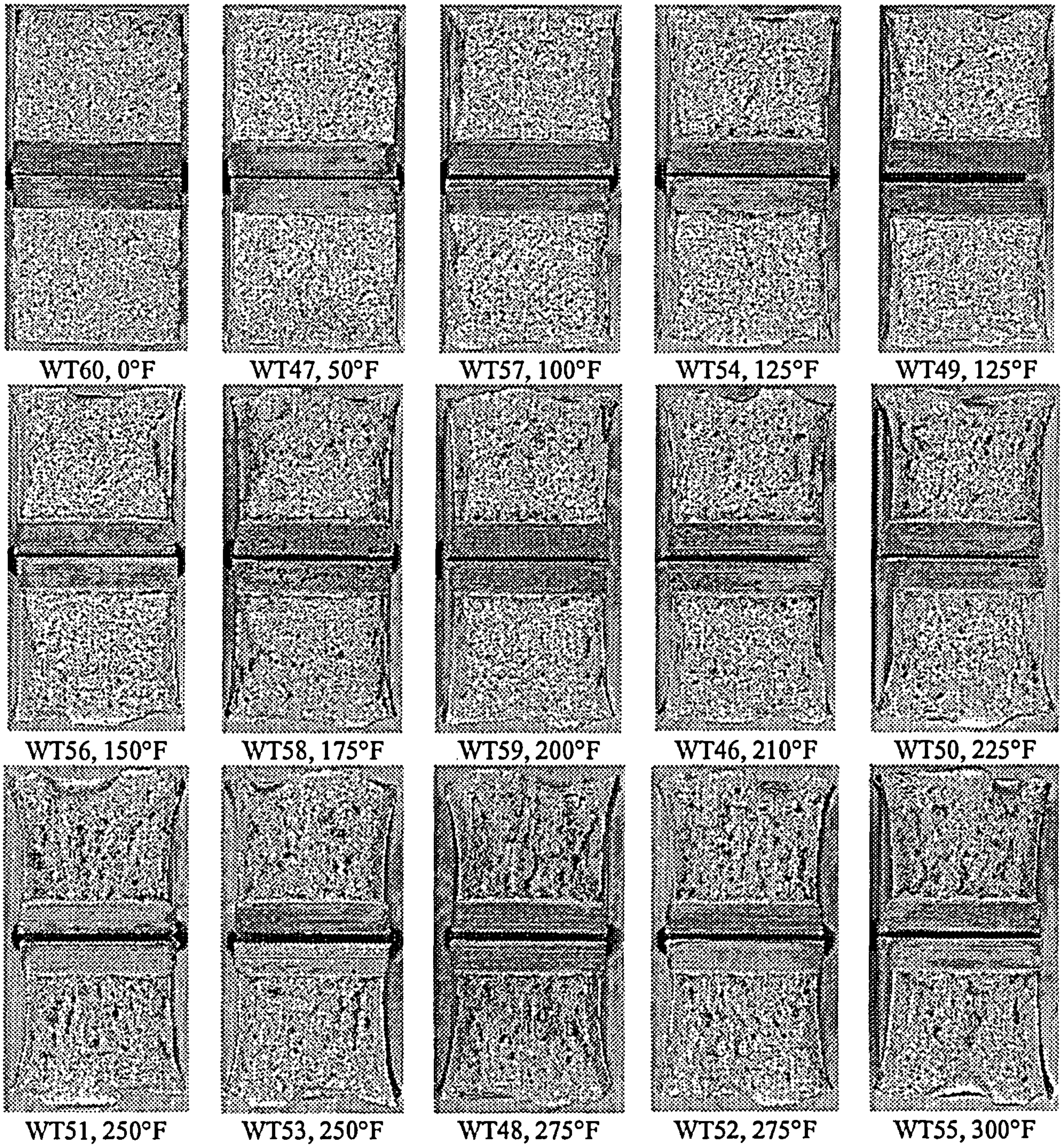


Figure 5-14 Charpy Impact Specimen Fracture Surfaces for Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Axial Orientation)

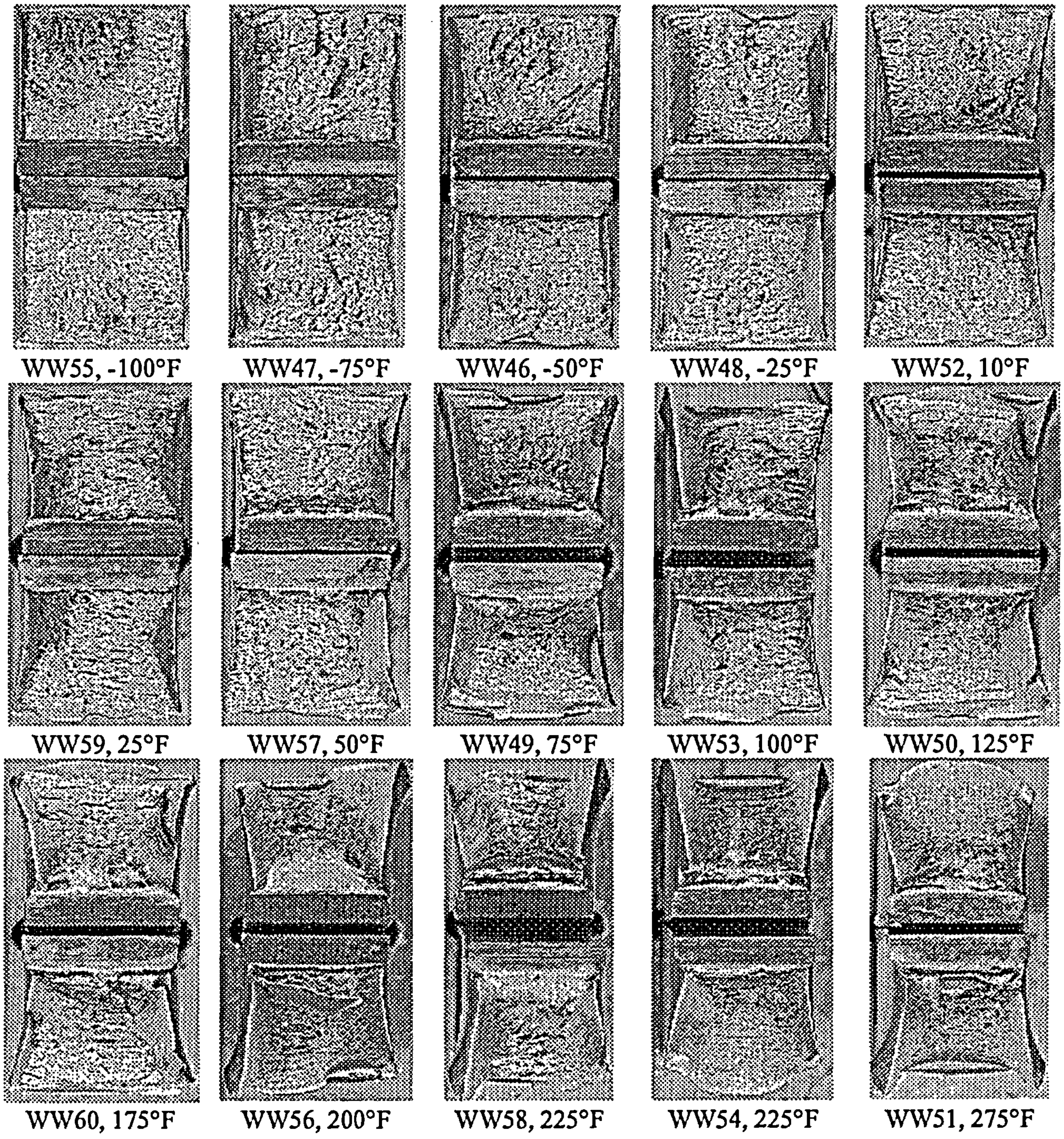


Figure 5-15 Charpy Impact Specimen Fractures Surfaces for Watts Bar Unit 1 Reactor Vessel Weld Metal

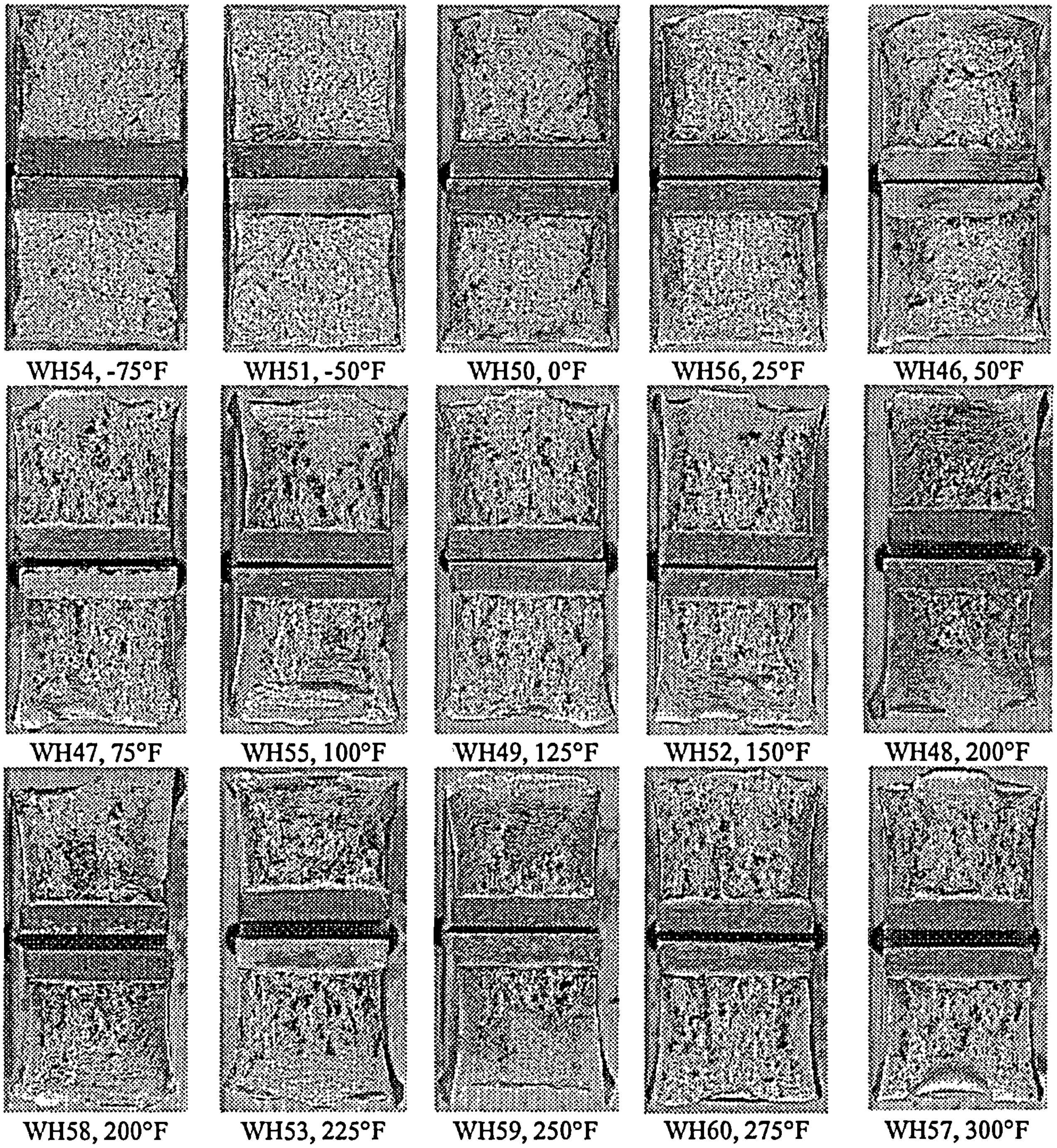
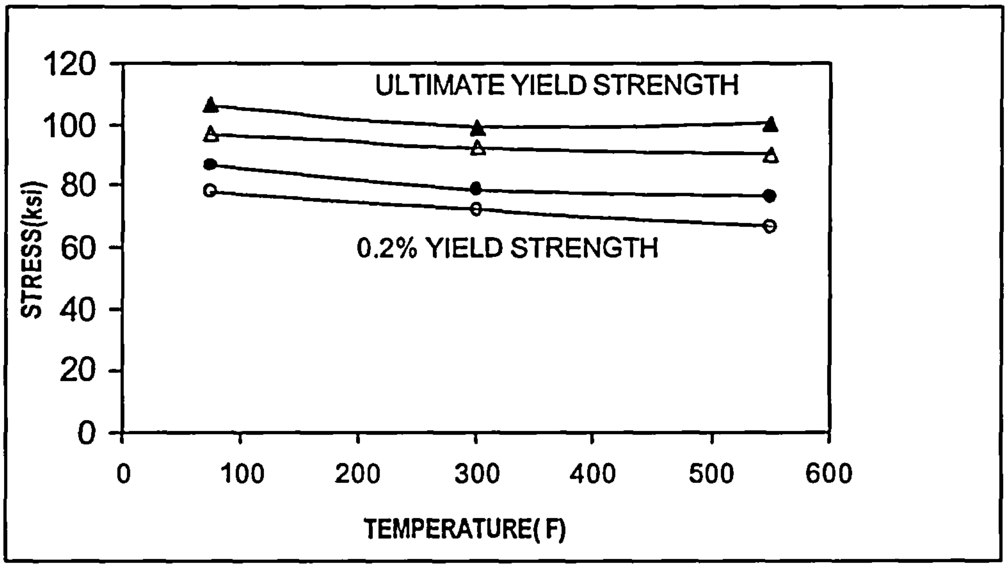


Figure 5-16 Charpy Impact Specimen Fracture Surfaces for Watts Bar Unit 1 Reactor Vessel Heat-Affected-Zone Metal



Legend: ? and ? are Unirradiated
? and ? are Irradiated to 1.71 x 10^{19} n/cm^2 (E > 1.0 MeV)

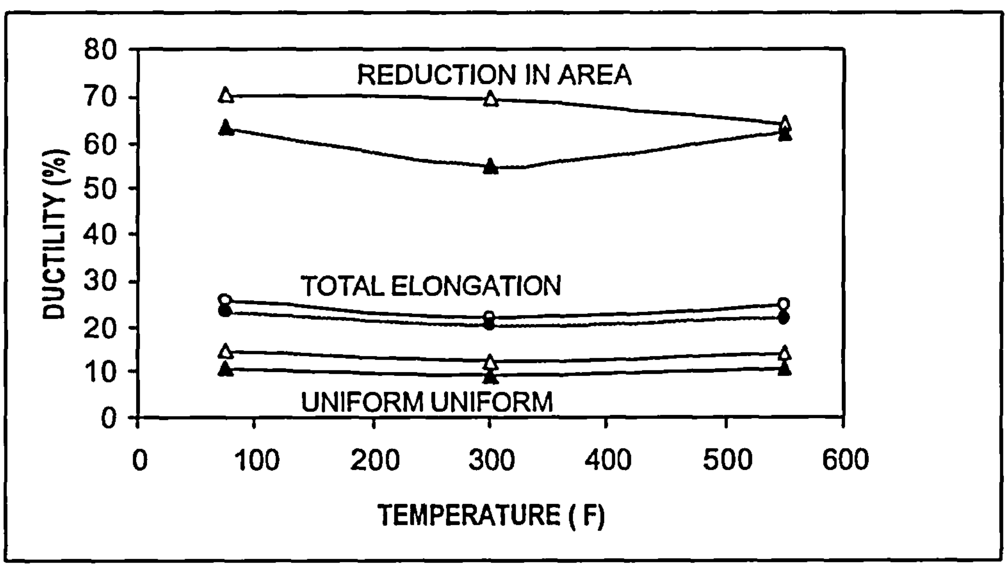
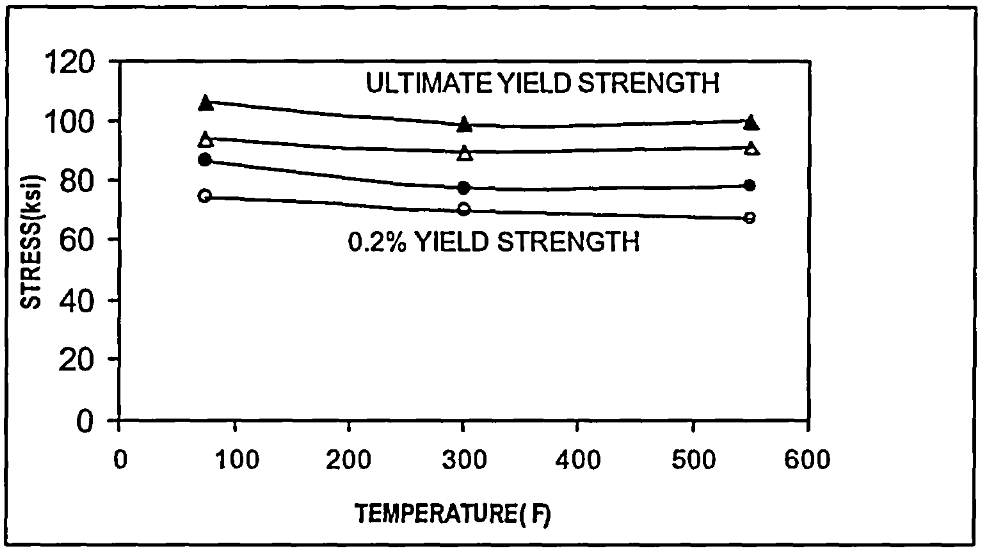


Figure 5-17 Tensile Properties for Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Tangential Orientation)



Legend: ? and ? are Unirradiated
? and ? are Irradiated to 1.71 x 10^{19} n/cm^2 (E > 1.0 MeV)

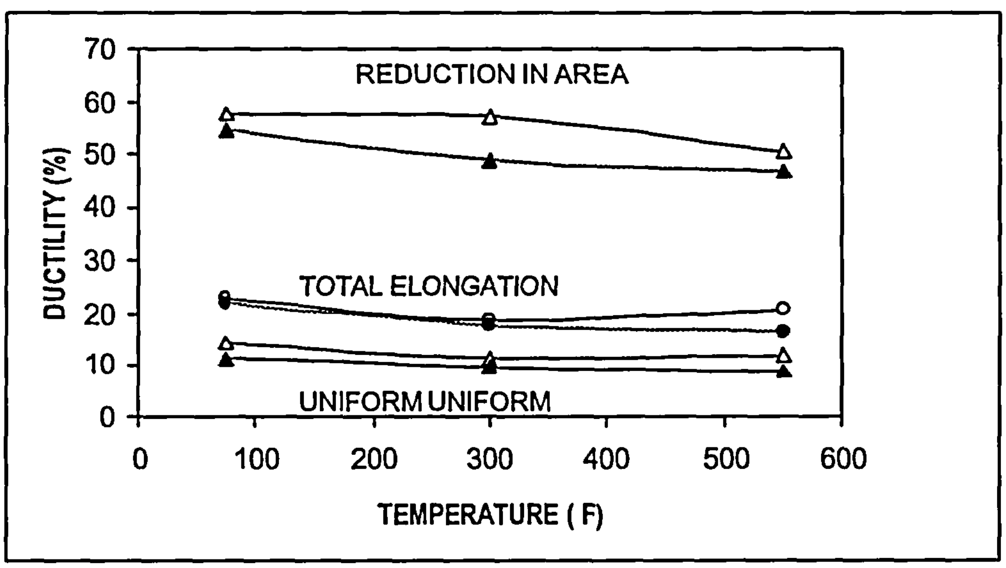
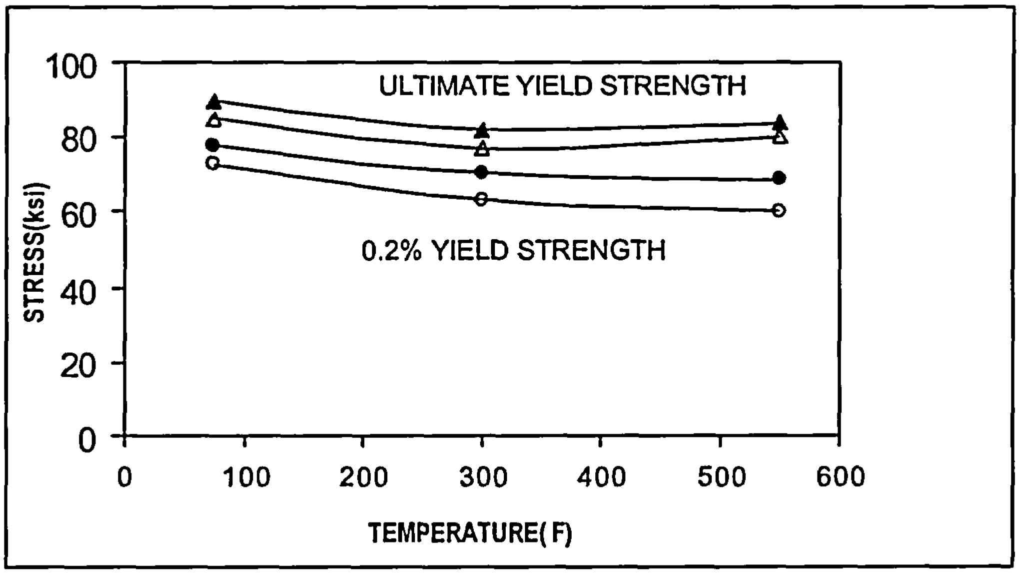


Figure 5-18 Tensile Properties for Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Axial Orientation)



Legend: ? and ? are Unirradiated
? and ? are Irradiated to 1.71 x 10^{19} n/cm^2 (E > 1.0 MeV)

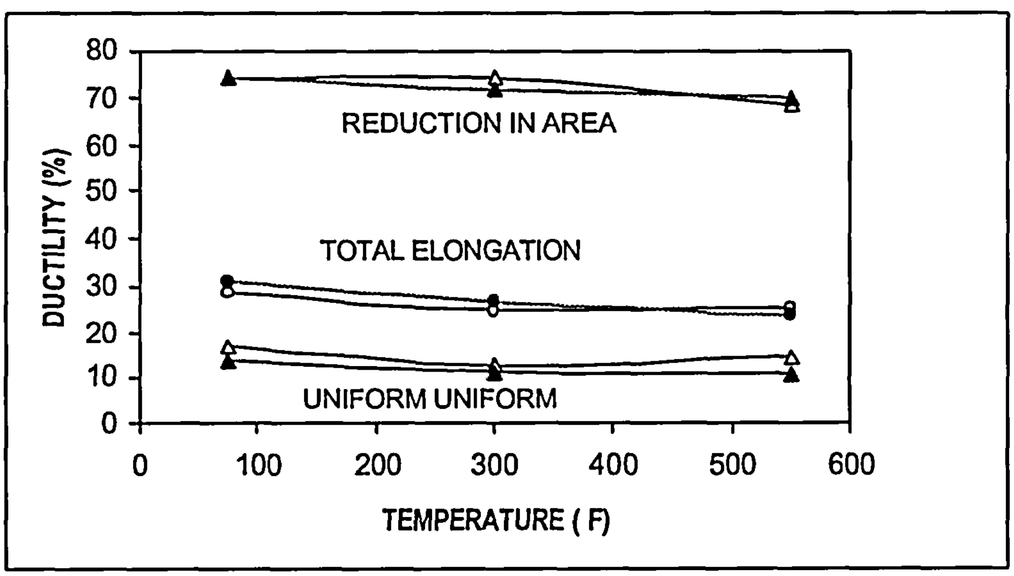
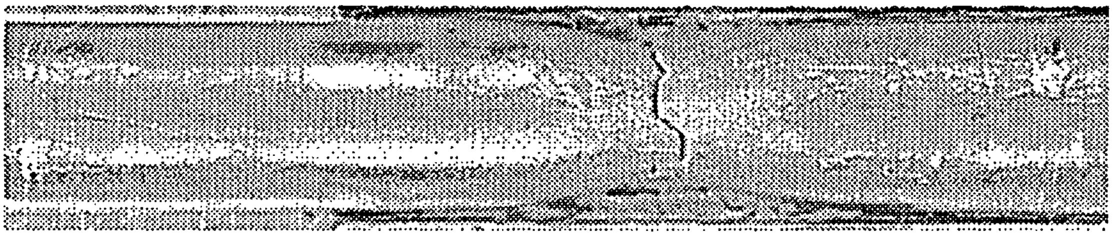
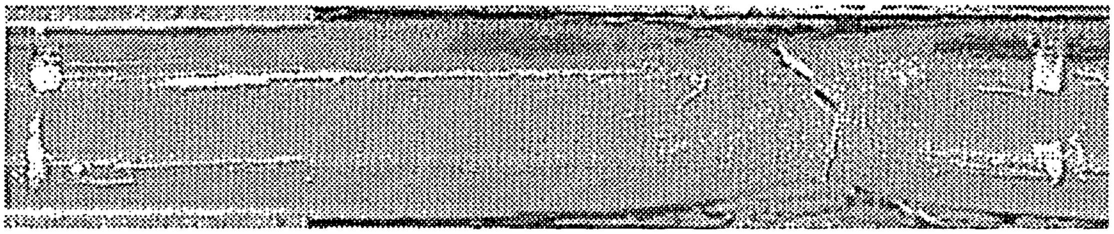


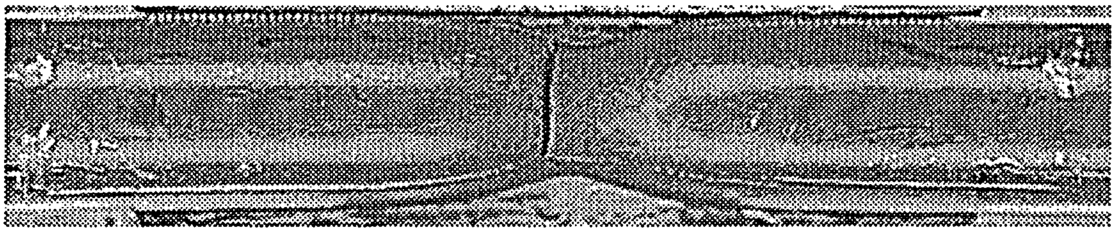
Figure 5-19 Tensile Properties for Watts Bar Unit 1 Reactor Vessel Weld Metal



Specimen WL-10 Tested at 75°F

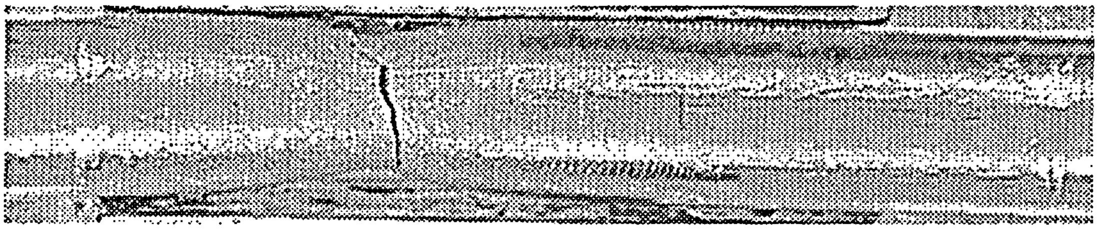


Specimen WL-11 Tested at 300°F

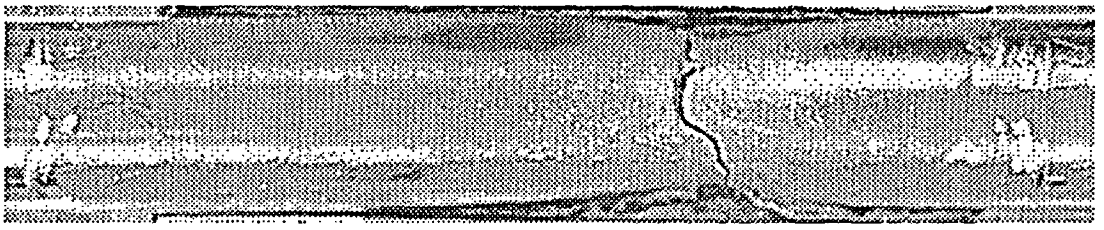


Specimen WL-12 Tested at 550°F

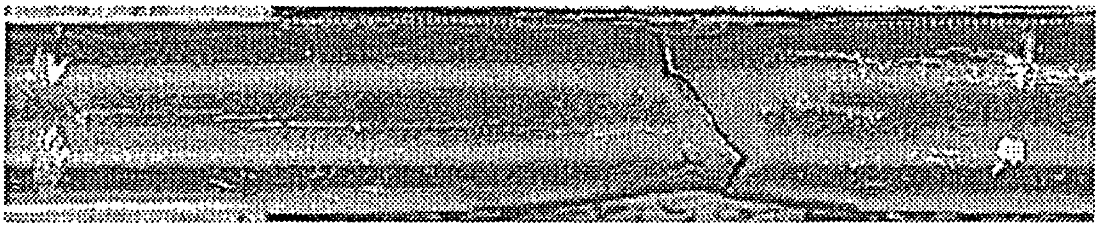
Figure 5-20 Fractured Tensile Specimens from Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Tangential Orientation)



Specimen WT-10 Tested at 75°F

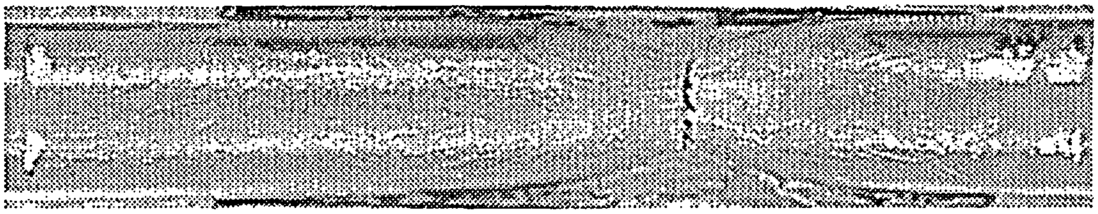


Specimen WT-11 Tested at 300°F

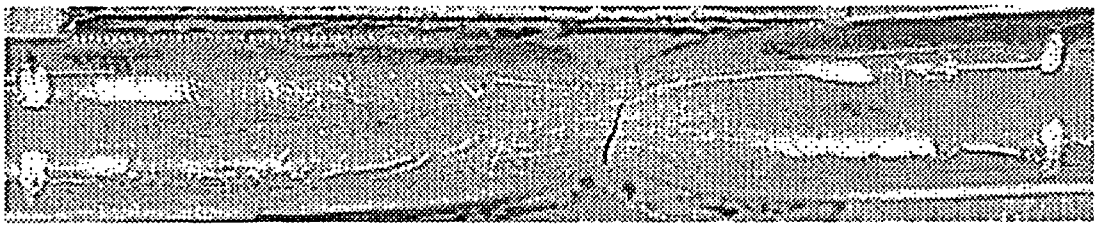


Specimen WT-12 Tested at 550°F

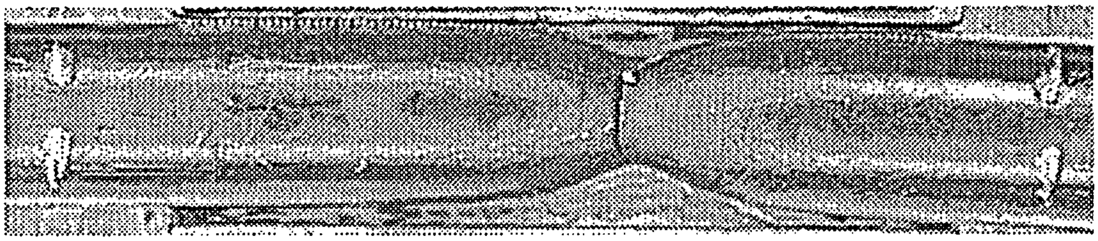
Figure 5-21 Fractured Tensile Specimens from Watts Bar Unit 1 Reactor Vessel Intermediate Shell Forging 05 (Axial Orientation)



Specimen WW-10 Tested at 75°F

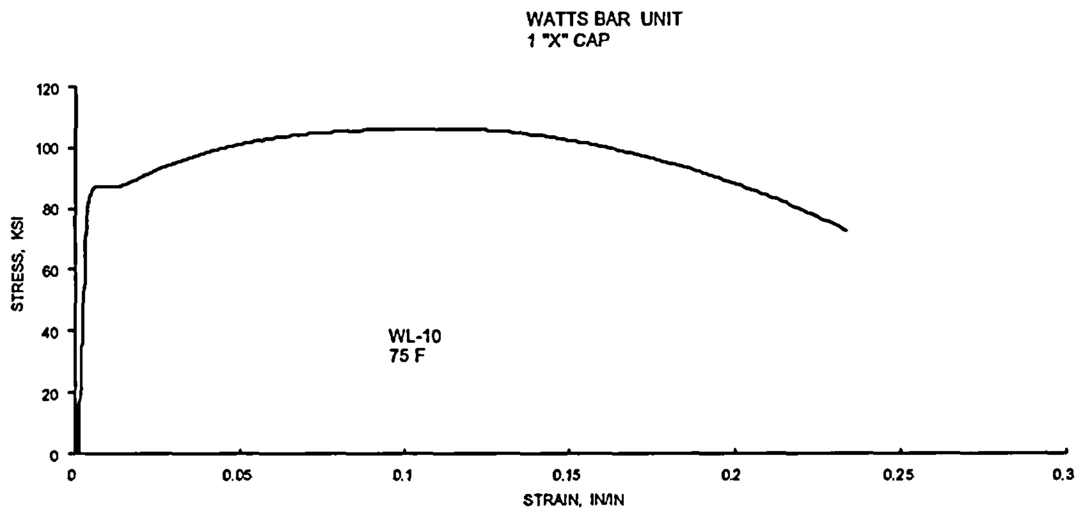


Specimen WW-11 Tested at 300°F



Specimen WW-12 Tested at 550°F

Figure 5-22 Fractured Tensile Specimens from Watts Bar Unit 1 Reactor Vessel Weld Metal



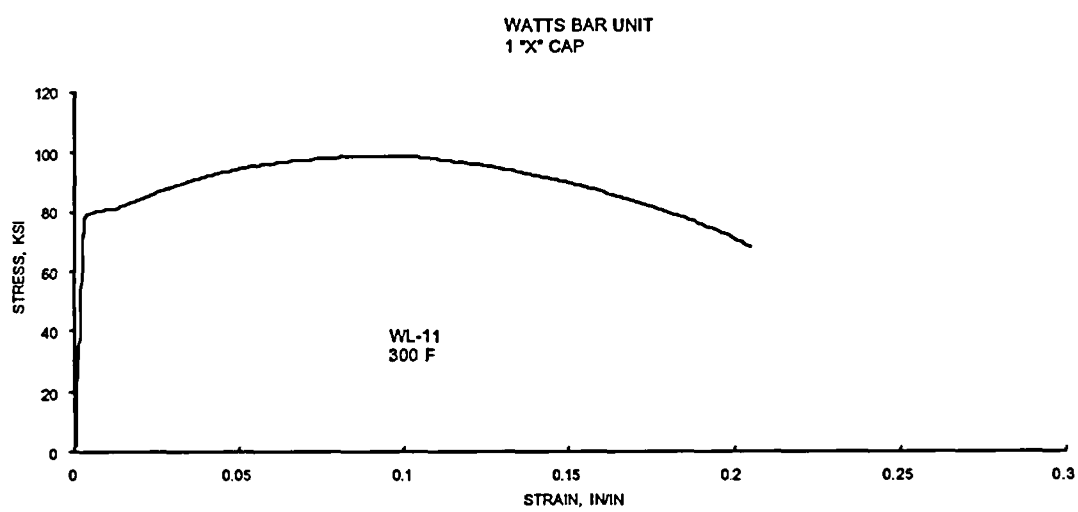


Figure 5-23 Engineering Stress-Strain Curves for Watts Bar Unit 1 Intermediate Shell Forging 05 Tensile Specimens WL-10, WL-11 and WL-12 (Tangential Orientation)

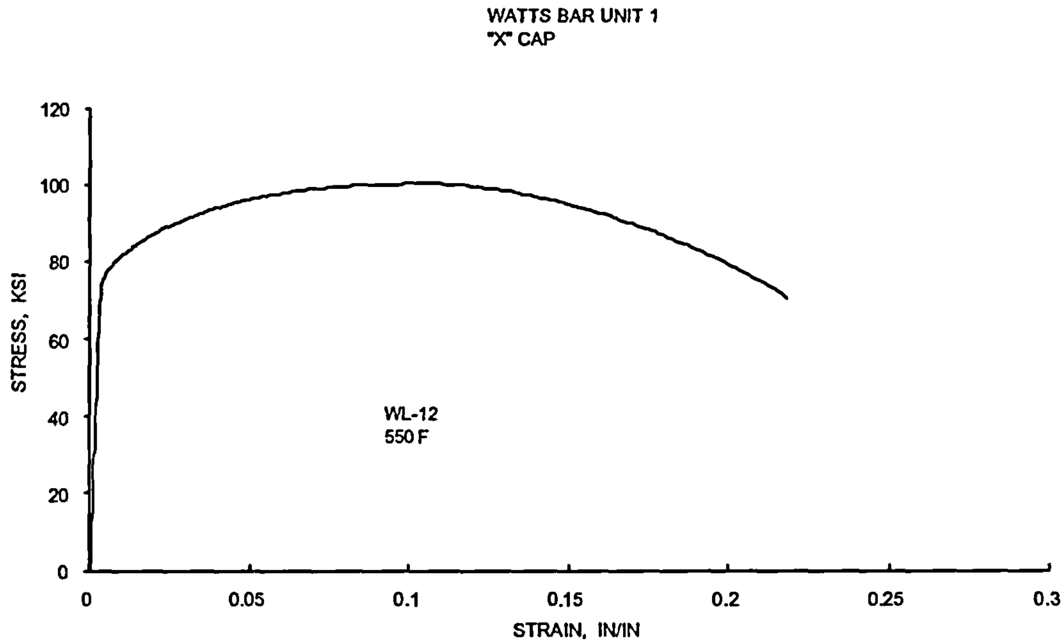
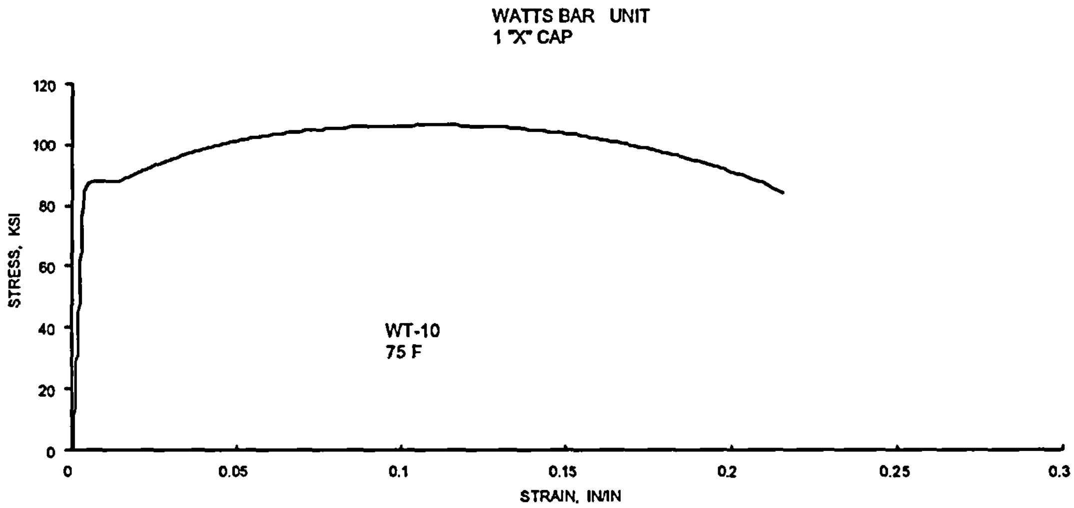


Figure 5-23 - Continued



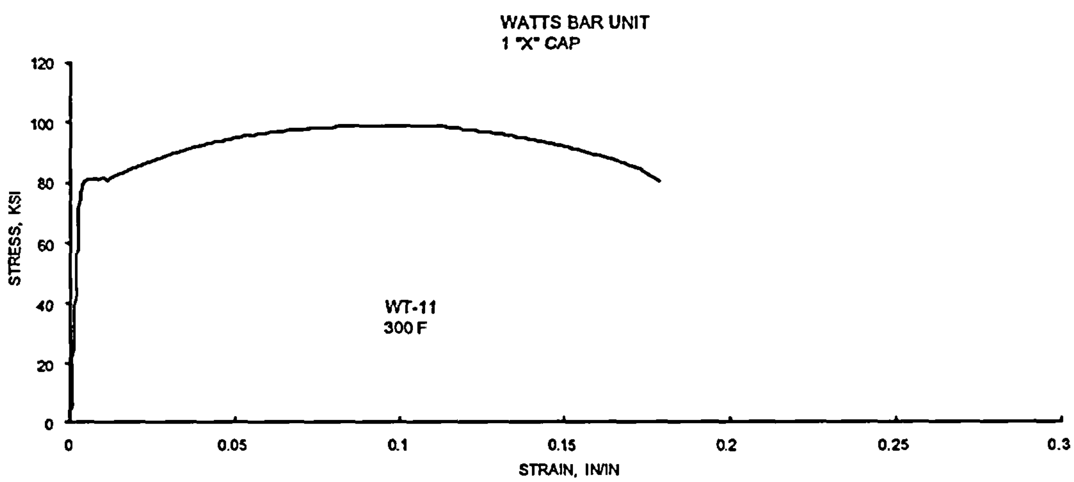


Figure 5-24 Engineering Stress-Strain Curves for Watts Bar Unit 1 Intermediate Shell Forging 05 Tensile Specimens WT-10, WT-11 and WT-12 (Axial Orientation)

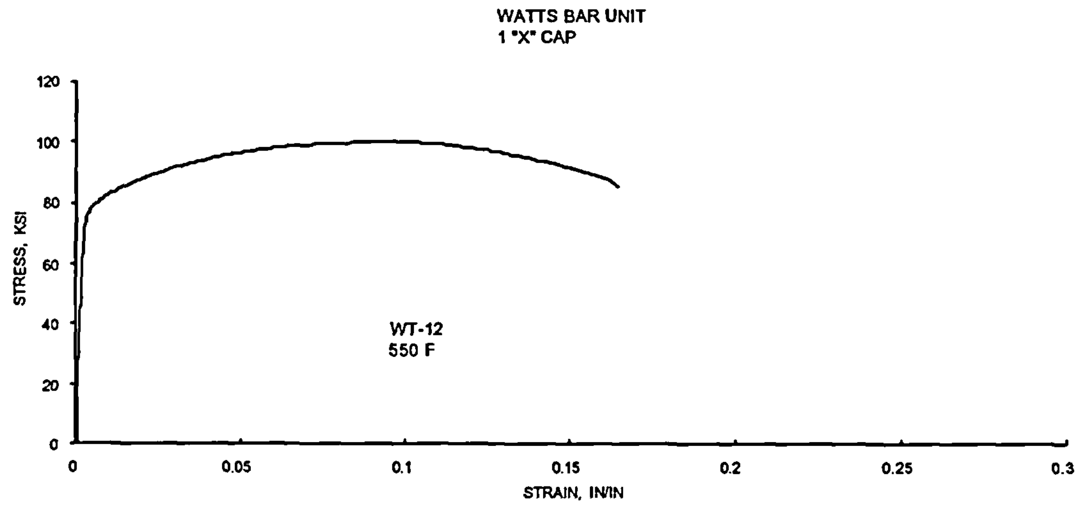
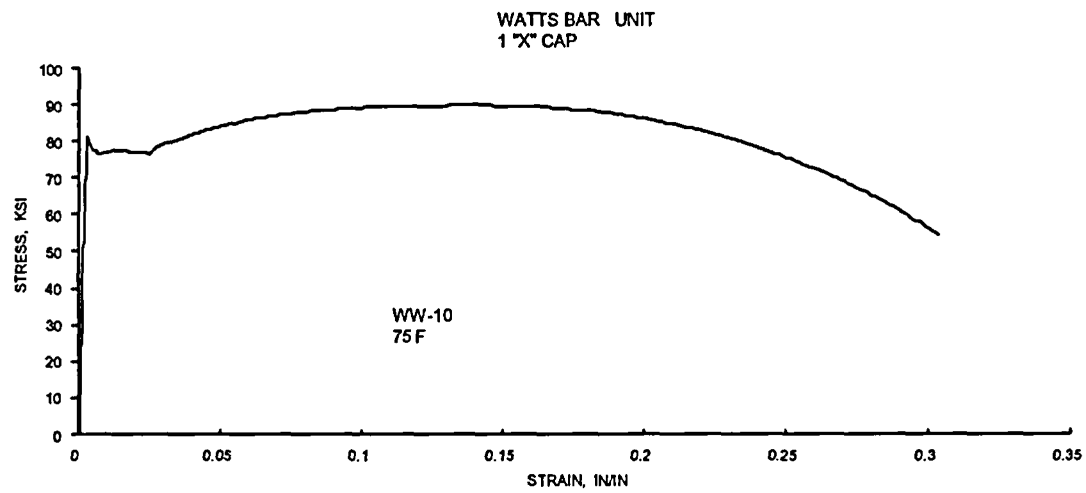


Figure 5-24 - Continued



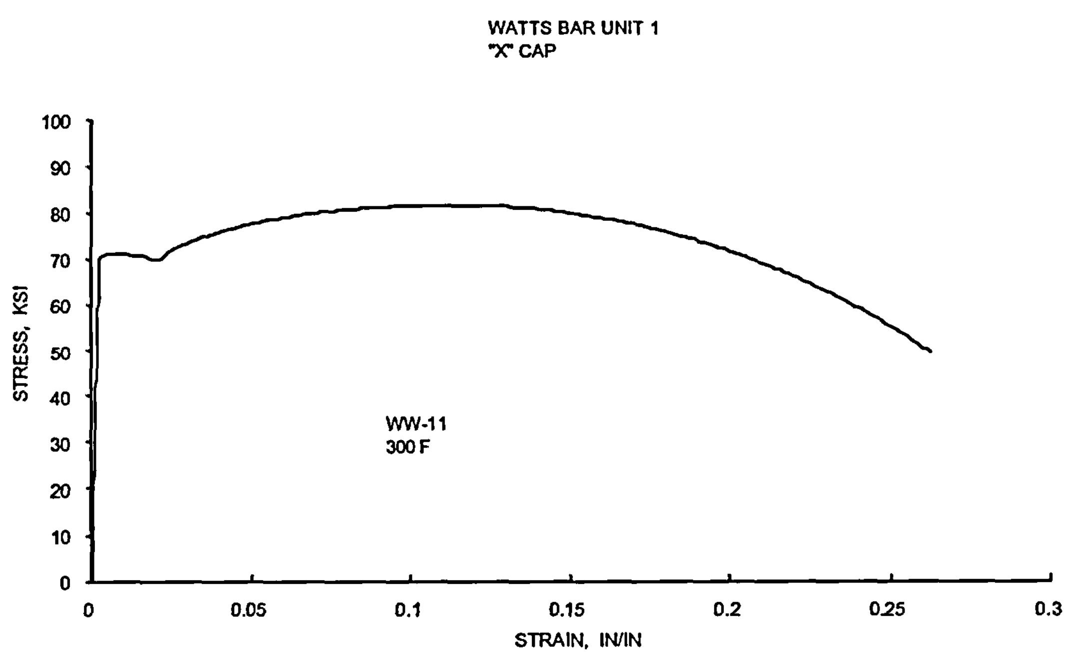


Figure 5-25 Engineering Stress-Strain Curves for Weld Metal Tensile Specimens WW-10, WW-11 and WW-12

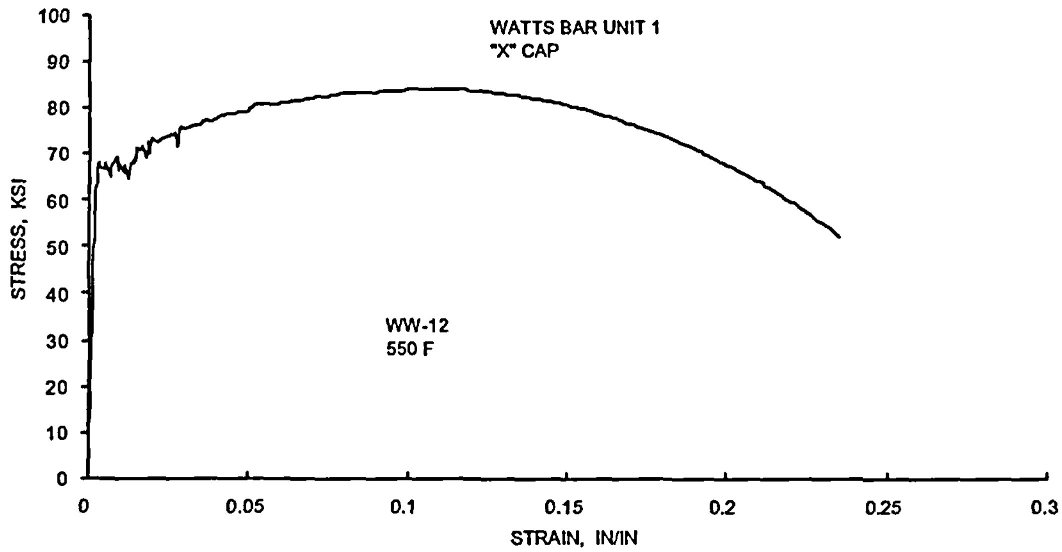


Figure 5-25 - Continued

6 RADIATION ANALYSIS AND NEUTRON DOSIMETRY

6.1 INTRODUCTION

This section describes a discrete ordinates S_n transport analysis performed for the Watts Bar Unit 1 reactor to determine the neutron radiation environment within the reactor pressure vessel and surveillance capsules. In this analysis, fast neutron exposure parameters in terms of fast neutron fluence (E > 1.0 MeV) and iron atom displacements (dpa) were established on a plant and fuel cycle specific basis. An evaluation of the most recent dosimetry sensor set from Capsule X, withdrawn at the end of the fifth plant operating cycle, is provided. In addition, to provide an up-to-date data base applicable to the Watts Bar Unit 1 reactor, sensor sets from previously withdrawn capsules (U, and W) were re-analyzed using the current dosimetry evaluation methodology. These dosimetry updates are presented in Appendix A of this report. Comparisons of the results from these dosimetry evaluations with the analytical predictions served to validate the plant specific neutron transport calculations. These validated calculations subsequently formed the basis for providing projections of the neutron exposure of the reactor pressure vessel for operating periods extending to 60 Effective Full Power Years (EFPY).

The use of fast neutron fluence (E > 1.0 MeV) to correlate measured material property changes to the neutron exposure of the material has traditionally been accepted for the development of damage trend curves as well as for the implementation of trend curve data to assess the condition of the vessel. In recent years, however, it has been suggested that an exposure model that accounts for differences in neutron energy spectra between surveillance capsule locations and positions within the vessel wall could lead to an improvement in the uncertainties associated with damage trend curves and improved accuracy in the evaluation of damage gradients through the reactor vessel wall.

Because of this potential shift away from a threshold fluence toward an energy dependent damage function for data correlation, ASTM Standard Practice E853, "Analysis and Interpretation of Light-Water Reactor Surveillance Results," recommends reporting displacements per iron atom (dpa) along with fluence (E > 1.0 MeV) to provide a database for future reference. The energy dependent dpa function to be used for this evaluation is specified in ASTM Standard Practice E693, "Characterizing Neutron Exposures in Iron and Low Alloy Steels in Terms of Displacements per Atom." The application of the dpa parameter to the assessment of embrittlement gradients through the thickness of the reactor vessel wall has already been promulgated in Revision 2 to Regulatory Guide 1.99, "Radiation Embrittlement of Reactor Vessel Materials."

All of the calculations and dosimetry evaluations described in this section and in Appendix A were based on the latest available nuclear cross-section data derived from ENDF/B-VI and made use of the latest available calculational tools. Furthermore, the neutron transport and dosimetry evaluation methodologies follow the guidance and meet the requirements of Regulatory Guide 1.190, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence,"[19]. Additionally, the methods used to develop the calculated pressure vessel fluence are consistent with the NRC approved methodology described in WCAP-14040-NP-A, "Methodology Used to Develop Cold Overpressure Mitigating System Setpoints and RCS Heatup and Cooldown Limit Curves," January 1996[20]. The specific calculational methods applied are also consistent with those described in WCAP-15557, "Qualification of the Westinghouse Pressure Vessel Neutron Fluence Evaluation Methodology." [20]

6.2 DISCRETE ORDINATES ANALYSIS

A plan view of the Watts Bar Unit 1 reactor geometry at the core midplane is shown in Figure 4-1. Six irradiation capsules attached to the neutron pad are included in the reactor design that constitutes the reactor vessel surveillance program. The capsules are located at azimuthal angles of 56° and 236° (dual capsule holder - 34° from the core cardinal axes), 58.5° and 238.5° (dual capsule holder - 31.5° from the core cardinal axes) and 124° and 304° (single capsule holder - 34° from the core cardinal axes). The stainless steel specimen containers are 1.182-inch by 1-inch and are approximately 56 inches in height. The containers are positioned axially such that the test specimens are centered on the core midplane, thus spanning the central 5 feet of the 12-foot high reactor core.

From a neutronic standpoint, the surveillance capsules and associated support structures are significant. The presence of these materials has a marked effect on both the spatial distribution of neutron flux and the neutron energy spectrum in the water annulus between the neutron pads and the reactor vessel. In order to determine the neutron environment at the test specimen location, the capsules themselves must be included in the analytical model.

In performing the fast neutron exposure evaluations for the Watts Bar Unit 1 reactor vessel and surveillance capsules, a series of fuel cycle specific forward transport calculations were carried out using the following three-dimensional flux synthesis technique:

$$\phi(r,\theta,z)=\phi(r,\theta)*\frac{\phi(r,z)}{\phi(r)}$$

where $\phi(r,\theta,z)$ is the synthesized three-dimensional neutron flux distribution, $\phi(r,\theta)$ is the transport solution in r,θ geometry, $\phi(r,z)$ is the two-dimensional solution for a cylindrical reactor model using the actual axial core power distribution, and $\phi(r)$ is the one-dimensional solution for a cylindrical reactor model using the same source per unit height as that used in the r,θ two-dimensional calculation. This synthesis procedure was carried out for each operating cycle at Watts Bar Unit 1.

For the Watts Bar Unit 1 transport calculations, three octant symmetric r,θ models were developed and are depicted in Figure 6-1. The first model contained the shortened neutron pad (15° span) with no surveillance capsules. The second model contained the medium neutron pad (17.5° span) including the single holder surveillance capsules. The third model contained the extended neutron pad (20° span) including the dual holder surveillance capsules. The first model was used to generate the maximum fluence at the pressure vessel wall. The two other models were to perform surveillance capsule dosimetry evaluations and subsequent comparisons with calculated results. In developing these analytical models, nominal design dimensions were employed for the various structural components. Likewise, water temperatures, and hence, coolant densities in the reactor core and downcomer regions of the reactor were taken to be representative of full power operating conditions. The coolant densities were treated on a fuel cycle specific basis. The reactor core itself was treated as a homogeneous mixture of fuel, cladding, water, and miscellaneous core structures such as fuel assembly grids, guide tubes, etc. The geometric mesh description of the r,θ reactor models consisted of 170 radial by 98 azimuthal intervals. Mesh sizes were chosen to assure that proper convergence of the inner iterations was achieved on a pointwise basis. The pointwise inner iteration flux convergence criterion utilized in the r,θ calculations was set at a value of 0.001.

The r,z model used for the Watts Bar Unit 1 calculations is shown in Figure 6-2 and extends radially from the centerline of the reactor core out to a location interior to the primary biological shield and over an axial span from an elevation 1-foot below the active fuel to approximately 1-foot above the active fuel. As in the case of the r,θ models, nominal design dimensions and full power coolant densities were employed in the calculations. In this case, the homogenous core region was treated as an equivalent cylinder with a volume equal to that of the active core zone. The stainless steel former plates located between the core baffle and core barrel regions were also explicitly included in the model. The r,z geometric mesh description of these reactor models consisted of 153 radial by 90 axial intervals. As in the case of the r,θ calculations, mesh sizes were chosen to assure that proper convergence of the inner iterations was achieved on a pointwise basis. The pointwise inner iteration flux convergence criterion utilized in the r,z calculations was also set at a value of 0.001.

The one-dimensional radial models used in the synthesis procedure consisted of the same 153 radial mesh intervals included in the r,z models. Thus, radial synthesis factors could be determined on a meshwise basis throughout the entire geometry.

The core power distributions used in the plant specific transport analysis were taken from the appropriate Watts Bar Unit 1 fuel cycle design reports. The data extracted from the design reports represented cycle dependent fuel assembly enrichments, burnups, and axial power distributions. This information was used to develop spatial and energy dependent core source distributions averaged over each individual fuel cycle. Therefore, the results from the neutron transport calculations provided data in terms of fuel cycle averaged neutron flux, which when multiplied by the appropriate fuel cycle length, generated the incremental fast neutron exposure for each fuel cycle. In constructing these core source distributions, the energy distribution of the source was based on an appropriate fission split for uranium and plutonium isotopes based on the initial enrichment and burnup history of individual fuel assemblies. From these assembly dependent fission splits, composite values of energy release per fission, neutron yield per fission, and fission spectrum were determined.

All of the transport calculations supporting this analysis were carried out using the DORT discrete ordinates code Version 3.1[22] and the BUGLE-96 cross-section library.[23] The BUGLE-96 library provides a 67 group coupled neutron-gamma ray cross-section data set produced specifically for light water reactor (LWR) applications. In these analyses, anisotropic scattering was treated with a P_5 legendre expansion and angular discretization was modeled with an S_{16} order of angular quadrature. Energy and space dependent core power distributions, as well as system operating temperatures, were treated on a fuel cycle specific basis.

Selected results from the neutron transport analyses are provided in Tables 6-1 through 6-6. In Table 6-1, the calculated exposure rates and integrated exposures, expressed in terms of both neutron fluence ($E > 1.0$ MeV) and dpa, are given at the radial and azimuthal center of the two azimuthally symmetric surveillance capsule positions (31.5° and 34°). These results, representative of the axial midplane of the active core, establish the calculated exposure of the surveillance capsules withdrawn to date as well as projected into the future. Similar information is provided in Tables 6-2 for the reactor vessel inner radius. The vessel data given in Table 6-2 are representative of the axial location of the maximum neutron exposure at each of the four azimuthal locations. It is also important to note that the data for the vessel inner radius were taken at the clad/base metal interface, and thus, represent the maximum calculated exposure levels of the vessel plates and welds.

Both calculated fluence (E > 1.0 MeV) and dpa data are provided in Table 6-1 through Table 6-3. These data tabulations include both plant and fuel cycle specific calculated neutron exposures at the end of the fifth operating fuel cycle as well as projections for the current operating fuel cycle, i.e., Cycle 6, and future projections to 15, 25, 32, 36, 40, 48, 54 and 60 EFPY. The projections were based on the assumption that the core power distributions and associated plant operating characteristics from Cycle 6 were representative of future plant operation. The future projections are also based on the current reactor power level of 3459 MWt.

Radial gradient information applicable to fast (E > 1.0 MeV) neutron fluence and dpa are given in Tables 6-3 and 6-4, respectively. The data, based on the cumulative integrated exposures from Cycles 1 through 6, are presented on a relative basis for each exposure parameter at several azimuthal locations. Exposure distributions through the vessel wall may be obtained by multiplying the calculated exposure at the vessel inner radius by the gradient data listed in Tables 6-3 and 6-4.

The calculated fast neutron exposures for the three surveillance capsules withdrawn from the Watts Bar Unit 1 reactor are provided in Table 6-5. These assigned neutron exposure levels are based on the plant and fuel cycle specific neutron transport calculations performed for the Watts Bar Unit 1 reactor.

Updated lead factors for the Watts Bar Unit 1 surveillance capsules are provided in Table 6-6. The capsule lead factor is defined as the ratio of the calculated fluence (E > 1.0 MeV) at the geometric center of the surveillance capsule to the corresponding maximum calculated fluence at the pressure vessel clad/base metal interface. In Table 6-6, the lead factors for capsules that have been withdrawn from the reactor (U, W, and X) were based on the calculated fluence values for the irradiation period corresponding to the time of withdrawal for the individual capsules. For the capsule remaining in the reactor (Y, V, and Z), the lead factor corresponds to the calculated fluence values at the end of Cycle 6, the current operating fuel cycle for Watts Bar Unit 1.

6.3 NEUTRON DOSIMETRY

The validity of the calculated neutron exposures previously reported in Section 6.2 is demonstrated by a direct comparison against the measured sensor reaction rates and via a least squares evaluation performed for each of the capsule dosimetry sets. However, since the neutron dosimetry measurement data merely serves to validate the calculated results, only the direct comparison of measured-to-calculated results for the most recent surveillance capsule removed from service is provided in this section of the report. For completeness, the assessment of all measured dosimetry removed to date, based on direct, best estimate, and least squares evaluation comparisons, is documented in Appendix A.

The direct comparison of measured versus calculated fast neutron threshold reaction rates for the sensors from Capsule X that was withdrawn from Watts Bar Unit 1 at the end of the twelfth fuel cycle, is summarized below.

Reaction	Reaction Rates (rps/atom)		M/C Ratio
	Measured	Calculated	
$^{63}Cu(n,\alpha)^{60}Co$	4.48E-17	4.07E-17	1.10
$^{54}Fe(n,p)^{54}Mn$	4.46E-15	4.65E-15	0.96
$^{58}Ni(n,p)^{58}Co$	6.69E-15	6.65E-15	1.02
$^{238}U(n,p)^{137}Cs$ (Cd)	2.47E-14	2.57E-14	0.96
$^{237}Np(n,f)^{137}Cs$ (Cd)	2.65E-13	2.59E-13	1.02
		Average:	1.01

The measured-to-calculated (M/C) reaction rate ratios for the Capsule X threshold reactions range from 0.96 to 1.10, and the average M/C ratio is 1.01 $\pm$ 5.8% (1σ). This direct comparison falls well within the $\pm$ 20% criterion specified in Regulatory Guide 1.190; furthermore, it is consistent with the full set of comparisons given in Appendix A for all measured dosimetry removed to date from the Watts Bar Unit 1 reactor. These comparisons validate the current analytical results described in Section 6.2; therefore, the calculations are deemed applicable for Watts Bar Unit 1.

6.4 CALCULATIONAL UNCERTAINTIES

The uncertainty associated with the calculated neutron exposure of the Watts Bar Unit 1 surveillance capsule and reactor pressure vessel is based on the recommended approach provided in Regulatory Guide 1.190. In particular, the qualification of the methodology was carried out in the following four stages:

1 - Comparison of calculations with benchmark measurements from the Pool Critical Assembly (PCA) simulator at the Oak Ridge National Laboratory (ORNL).

2 - Comparisons of calculations with surveillance capsule and reactor cavity measurements from the H. B. Robinson power reactor benchmark experiment.

3 - An analytical sensitivity study addressing the uncertainty components resulting important input parameters applicable to the plant specific transport calculations used in the neutron exposure assessments.

4 - Comparisons of the plant specific calculations with all available dosimetry results from the Watts Bar Unit 1 surveillance program.

The first phase of the methods qualification (PCA comparisons) addressed the adequacy of basic transport calculation and dosimetry evaluation techniques and associated cross-sections. This phase, however, did not test the accuracy of commercial core neutron source calculations nor did it address uncertainties in operational or geometric variables that impact power reactor calculations. The second phase of the qualification (H. B. Robinson comparisons) addressed uncertainties in these additional areas that are primarily methods related and would tend to apply generically to all fast neutron exposure evaluations. The third phase of the qualification (analytical sensitivity study) identified the potential uncertainties introduced into the overall evaluation due to calculational methods approximations as well as to a lack of knowledge relative to various plant specific input parameters. The overall calculational uncertainty applicable to the Watts Bar Unit 1 analysis was established from results of these three phases of the methods qualification.

The fourth phase of the uncertainty assessment (comparisons with Watts Bar Unit 1 measurements) was used solely to demonstrate the validity of the transport calculations and to confirm the uncertainty estimates associated with the analytical results. The comparison was used only as a check and was not used in any way to modify the calculated surveillance capsule and pressure vessel neutron exposures previously described in Section 6.2. As such, the validation of the Watts Bar Unit 1 analytical model based on the measured plant dosimetry is completely described in Appendix A.

The following summarizes the uncertainties developed from the first three phases of the methodology qualification. Additional information pertinent to these evaluations is provided in Reference 21.

	Capsule	Vessel IR
PCA Comparisons	3%	3%
H. B. Robinson Comparisons	3%	3%
Analytical Sensitivity Studies	10%	11%
Additional Uncertainty for Factors not Explicitly Evaluated	5%	5%
Net Calculational Uncertainty	12%	13%

The net calculational uncertainty was determined by combining the individual components in quadrature. Therefore, the resultant uncertainty was treated as random and no systematic bias was applied to the analytical results.

The plant specific measurement comparisons described in Appendix A support these uncertainty assessments for Watts Bar Unit 1.

Figure 6-1

Watts Bar Unit 1 r,θ Reactor Geometry with a 15° Neutron Pad at the Core Midplane

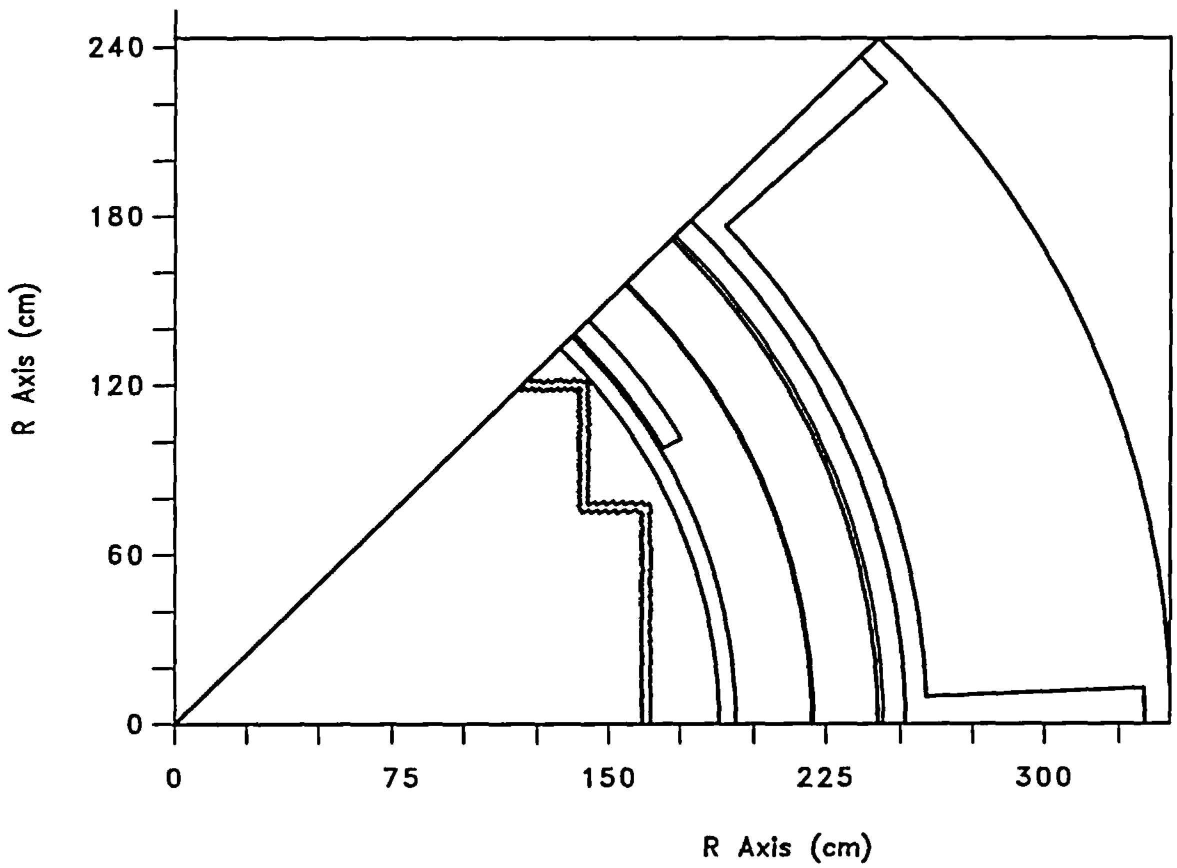


Figure 6-1 (continued)
Watts Bar Unit 1 r,θ Reactor Geometry with a 17.5° Neutron Pad at the Core Midplane

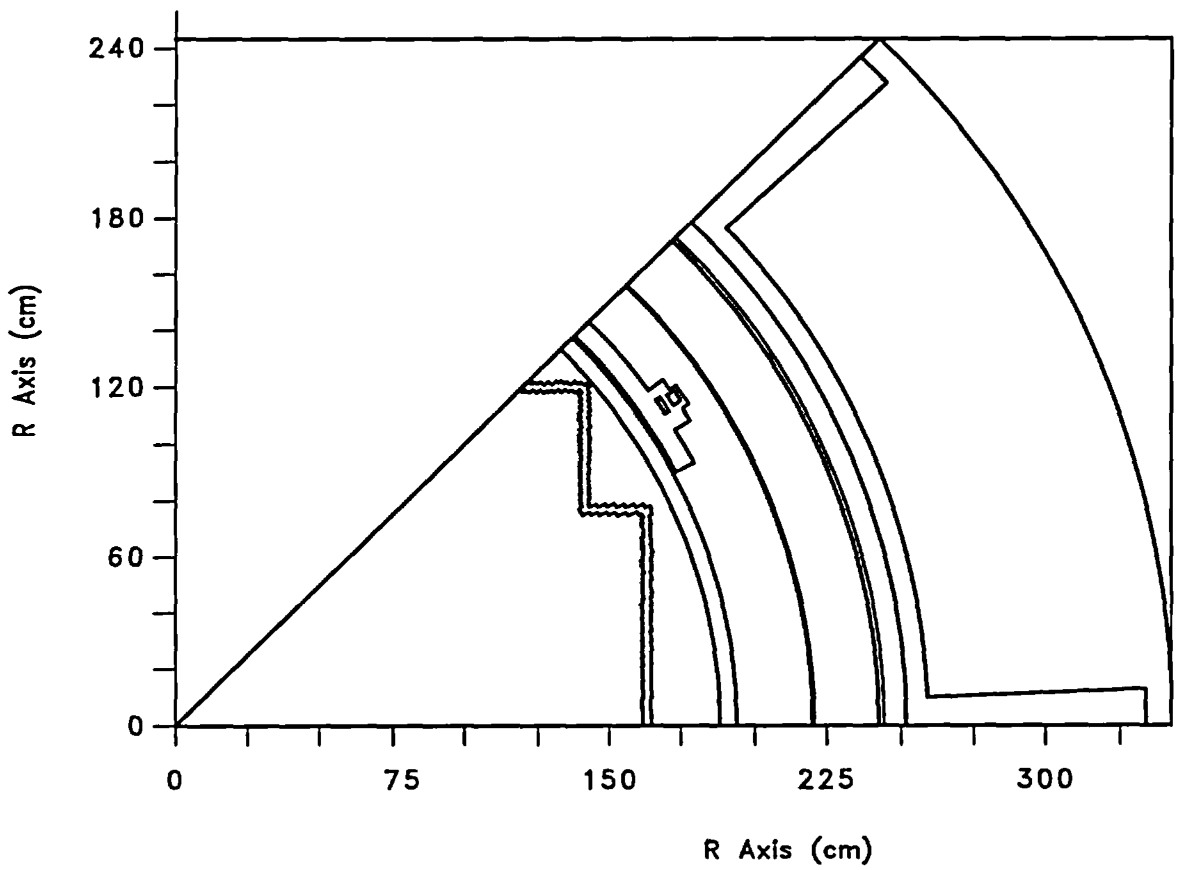


Figure 6-1 (continued)
Watts Bar Unit 1 r,θ Reactor Geometry with a 20° Neutron Pad at the Core Midplane

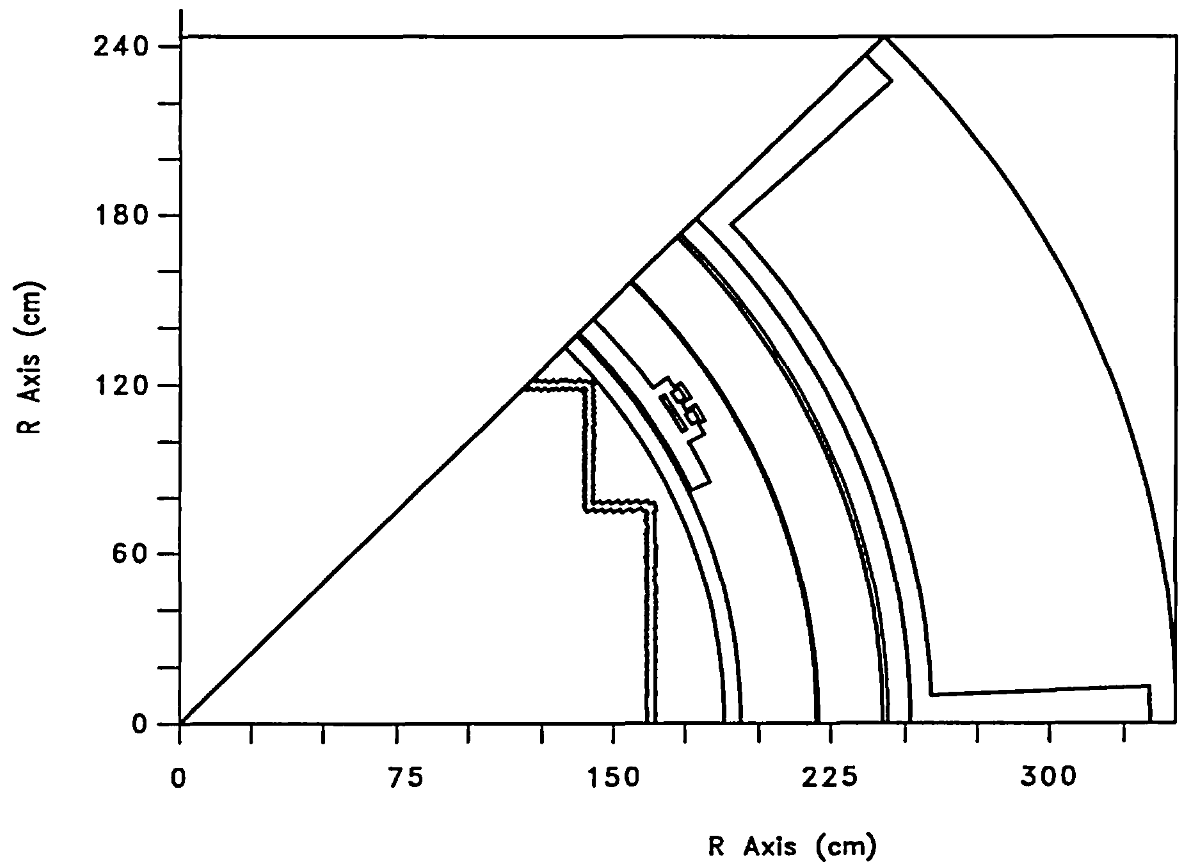


Figure 6-2

Watts Bar Unit 1 r,z Reactor Geometry with Neutron Pad

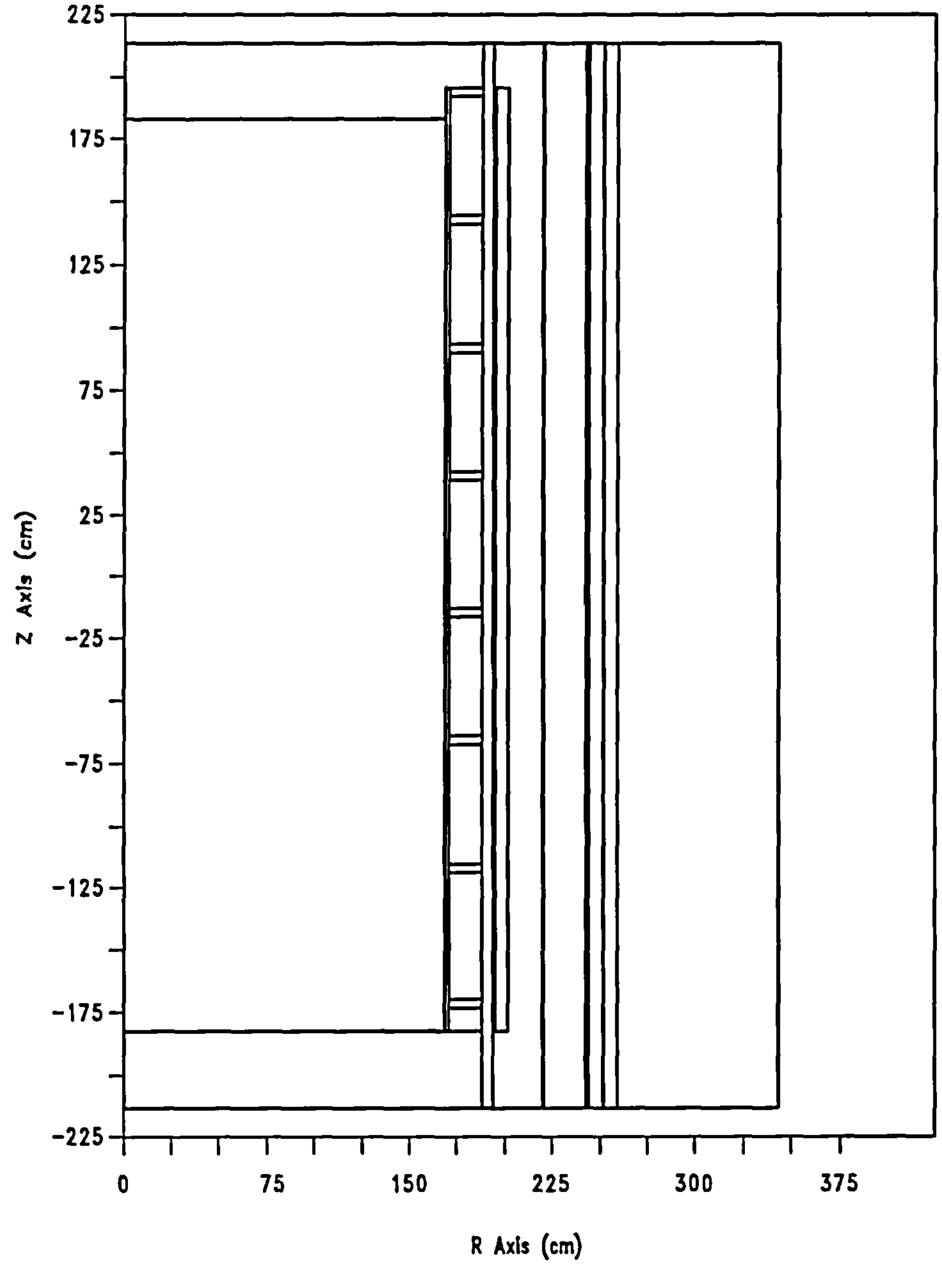


Table 6-1

Calculated Neutron Exposure Rates And Integrated Exposures
at the Surveillance Capsule Center

Neutrons Flux (E > 1.0 MeV)

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Neutron Flux (E > 1.0 MeV) [n/cm^2-s]		
				Dual 31.5°	Dual 34°	Single 34°
1	3.800E+07	3.800E+07	1.20	9.968E+10	1.176E+11	1.194E+11
2	4.073E+07	7.873E+07	2.49	6.404E+10	7.339E+10	7.444E+10
3	4.359E+07	1.223E+08	3.88	6.343E+10	7.284E+10	7.389E+10
4	4.217E+07	1.645E+08	5.21	7.275E+10	8.363E+10	8.483E+10
5	4.459E+07	2.091E+08	6.63	5.634E+10	6.520E+10	6.614E+10
6	4.593E+07	2.550E+08	8.08	6.198E+10	7.278E+10	7.385E+10
Future	2.183E-08	4.734E+08	15	6.198E+10	7.278E+10	7.385E+10
Future	3.156E+08	7.889E+08	25	6.198E+10	7.278E+10	7.385E+10
Future	2.209E+08	1.010E+09	32	6.198E+10	7.278E+10	7.385E+10
Future	1.262E+08	1.136E+09	36	6.198E+10	7.278E+10	7.385E+10
Future	1.262E+08	1.262E+09	40	6.198E+10	7.278E+10	7.385E+10
Future	2.525E+08	1.515E+09	48	6.198E+10	7.278E+10	7.385E+10
Future	1.893E+08	1.704E+09	54	6.198E+10	7.278E+10	7.385E+10
Future	1.893E+08	1.893E+09	60	6.198E+10	7.278E+10	7.385E+10

Note: Neutron exposure values reported for the surveillance capsules are centered at the core midplane.

Table 6-1 cont'd

Calculated Neutron Exposure Rates And Integrated Exposures
at the Surveillance Capsule Center

Cumulative Neutrons Fluence (E > 1.0 MeV)

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Neutron Fluence (E > 1.0 MeV) [n/cm^2-s]		
				Dual 31.5°	Dual 34°	Single 34°
1	3.800E+07	3.800E+07	1.20	3.788E+18	4.469E+18	4.536E+18
2	4.073E+07	7.873E+07	2.49	6.396E+18	7.459E+18	7.568E+18
3	4.359E+07	1.223E+08	3.88	9.161E+18	1.063E+19	1.079E+19
4	4.217E+07	1.645E+08	5.21	1.223E+19	1.416E+19	1.437E+19
5	4.459E+07	2.091E+08	6.63	1.474E+19	1.707E+19	1.731E+19
6	4.593E+07	2.550E+08	8.08	1.759E+19	2.041E+19	2.071E+19
Future	2.183E-08	4.734E+08	15	3.112E+19	3.630E+19	3.683E+19
Future	3.156E+08	7.889E+08	25	5.068E+19	5.927E+19	6.014E+19
Future	2.209E+08	1.010E+09	32	6.437E+19	7.535E+19	7.645E+19
Future	1.262E+08	1.136E+09	36	7.220E+19	8.453E+19	8.577E+19
Future	1.262E+08	1.262E+09	40	8.002E+19	9.372E+19	9.509E+19
Future	2.525E+08	1.515E+09	48	9.567E+19	1.121E+20	1.137E+20
Future	1.893E+08	1.704E+09	54	1.074E+20	1.259E+20	1.277E+20
Future	1.893E+08	1.893E+09	60	1.191E+20	1.397E+20	1.417E+20

Note: Neutron exposure values reported for the surveillance capsules are centered at the core midplane.

Table 6-1 cont'd

Calculated Neutron Exposure Rates And Integrated Exposures at the Surveillance Capsule Center

Iron Atom Displacement Rates

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Iron Displacement Rates (E > 1.0 MeV) [dpa/s]		
				Dual 31.5°	Dual 34°	Single 34°
1	3.800E+07	3.800E+07	1.20	1.964E-10	2.355E-10	2.438E-10
2	4.073E+07	7.873E+07	2.49	1.248E-10	1.453E-10	1.504E-10
3	4.359E+07	1.223E+08	3.88	1.234E-10	1.440E-10	1.489E-10
4	4.217E+07	1.645E+08	5.21	1.417E-10	1.654E-10	1.711E-10
5	4.459E+07	2.091E+08	6.63	1.096E-10	1.289E-10	1.334E-10
6	4.593E+07	2.550E+08	8.08	1.210E-10	1.443E-10	1.494E-10
Future	2.183E-08	4.734E+08	15	1.210E-10	1.443E-10	1.494E-10
Future	3.156E+08	7.889E+08	25	1.210E-10	1.443E-10	1.494E-10
Future	2.209E+08	1.010E+09	32	1.210E-10	1.443E-10	1.494E-10
Future	1.262E+08	1.136E+09	36	1.210E-10	1.443E-10	1.494E-10
Future	1.262E+08	1.262E+09	40	1.210E-10	1.443E-10	1.494E-10
Future	2.525E+08	1.515E+09	48	1.210E-10	1.443E-10	1.494E-10
Future	1.893E+08	1.704E+09	54	1.210E-10	1.443E-10	1.494E-10
Future	1.893E+08	1.893E+09	60	1.210E-10	1.443E-10	1.494E-10

Note: Neutron exposure values reported for the surveillance capsules are centered at the core midplane.

Table 6-1 cont'd

Calculated Neutron Exposure Rates And Integrated Exposures
at the Surveillance Capsule Center

Cumulative Iron Atom Displacements

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Iron Atom Displacements (E > 1.0 MeV) [dpa]		
				Dual 31.5°	Dual 34°	Single 34°
1	3.800E+07	3.800E+07	1.20	7.464E-03	8.949E-03	9.264E-03
2	4.073E+07	7.873E+07	2.49	1.255E-02	1.487E-02	1.539E-02
3	4.359E+07	1.223E+08	3.88	1.793E-02	2.114E-02	2.188E-02
4	4.217E+07	1.645E+08	5.21	2.390E-02	2.812E-02	2.910E-02
5	4.459E+07	2.091E+08	6.63	2.879E-02	3.387E-02	3.505E-02
6	4.593E+07	2.550E+08	8.08	3.434E-02	4.050E-02	4.191E-02
Future	2.183E-08	4.734E+08	15	6.075E-02	7.201E-02	7.451E-02
Future	3.156E+08	7.889E+08	25	9.892E-02	1.176E-01	1.217E-01
Future	2.209E+08	1.010E+09	32	1.256E-01	1.494E-01	1.547E-01
Future	1.262E+08	1.136E+09	36	1.409E-01	1.677E-01	1.735E-01
Future	1.262E+08	1.262E+09	40	1.562E-01	1.859E-01	1.924E-01
Future	2.525E+08	1.515E+09	48	1.867E-01	2.223E-01	2.301E-01
Future	1.893E+08	1.704E+09	54	2.096E-01	1.497E-01	2.584E-01
Future	1.893E+08	1.893E+09	60	2.325E-01	2.770E-01	2.866E-01

Note: Neutron exposure values reported for the surveillance capsules are centered at the core midplane.

Table 6-2

Calculated Azimuthal Variation of Maximum Exposure Rates
And Integrated Exposures at the Reactor Vessel
Clad/Base Metal Interface

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Neutron Flux (E > 1.0 MeV) [n/cm^2-s]			
				0°	15°	30°	45°
1	3.800E+07	3.800E+07	1.20	1.260E+10	1.916E+10	1.903E+10	2.353E+10
2	4.073E+07	7.873E+07	2.49	8.171E+09	1.270E+10	1.318E+10	1.522E+10
3	4.359E+07	1.223E+08	3.88	9.097E+09	1.253E+10	1.278E+10	1.494E+10
4	4.217E+07	1.645E+08	5.21	8.537E+09	1.263E+10	1.386E+10	1.625E+10
5	4.459E+07	2.091E+08	6.63	7.942E+09	1.062E+10	1.086E+10	1.320E+10
6	4.593E+07	2.550E+08	8.08	7.885E+09	1.137E+10	1.190E+10	1.501E+10
Future	2.183E-08	4.734E+08	15	7.885E+09	1.137E+10	1.190E+10	1.501E+10
Future	3.156E+08	7.889E+08	25	7.885E+09	1.137E+10	1.190E+10	1.501E+10
Future	2.209E+08	1.010E+09	32	7.885E+09	1.137E+10	1.190E+10	1.501E+10
Future	1.262E+08	1.136E+09	36	7.885E+09	1.137E+10	1.190E+10	1.501E+10
Future	1.262E+08	1.262E+09	40	7.885E+09	1.137E+10	1.190E+10	1.501E+10
Future	2.525E+08	1.515E+09	48	7.885E+09	1.137E+10	1.190E+10	1.501E+10
Future	1.893E+08	1.704E+09	54	7.885E+09	1.137E+10	1.190E+10	1.501E+10
Future	1.893E+08	1.893E+09	60	7.885E+09	1.137E+10	1.190E+10	1.501E+10

Table 6-2 cont'd

Calculated Azimuthal Variation of Maximum Exposure Rates
And Integrated Exposures at the Reactor Vessel
Clad/Base Metal Interface

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Neutron Fluence (E > 1.0 MeV) [n/cm^2]			
				0°	15°	30°	45°
1	3.800E+07	3.800E+07	1.20	4.786E+17	7.280E+17	7.299E+17	8.942E+17
2	4.073E+07	7.873E+07	2.49	7.962E+17	1.222E+18	1.237E+18	1.486E+18
3	4.359E+07	1.223E+08	3.88	1.192E+18	1.767E+18	1.792E+18	2.135E+18
4	4.217E+07	1.645E+08	5.21	1.546E+18	2.291E+18	2.368E+18	2.810E+18
5	4.459E+07	2.091E+08	6.63	1.896E+18	2.760E+18	2.847E+18	3.392E+18
6	4.593E+07	2.550E+08	8.08	2.259E+18	3.282E+18	3.394E+18	4.081E+18
Future	2.183E-08	4.734E+08	15	3.980E+18	5.763E+18	5.992E+18	7.357E+18
Future	3.156E+08	7.889E+08	25	6.468E+18	9.350E+18	9.748E+18	1.209E+19
Future	2.209E+08	1.010E+09	32	8.210E+18	1.186E+19	1.238E+19	1.541E+19
Future	1.262E+08	1.136E+09	36	9.205E+18	1.330E+19	1.388E+19	1.730E+19
Future	1.262E+08	1.262E+09	40	1.020E+19	1.473E+19	1.538E+19	1.919E+19
Future	2.525E+08	1.515E+09	48	1.219E+19	1.760E+19	1.839E+19	2.298E+19
Future	1.893E+08	1.704E+09	54	1.368E+19	1.975E+19	2.064E+19	2.582E+19
Future	1.893E+08	1.893E+09	60	1.518E+19	2.190E+19	2.289E+19	2.866E+19

Table 6-2 cont'd

Calculated Azimuthal Variation of Fast Neutron Exposure Rates
And Iron Atom Displacement Rates at the Reactor Vessel
Clad/Base Metal Interface

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Iron Atom Displacement Rate [dpa/s]			
				0°	15°	30°	45°
1	3.800E+07	3.800E+07	1.20	1.954E-11	2.945E-11	2.968E-11	3.729E-11
2	4.073E+07	7.873E+07	2.49	1.270E-11	1.955E-11	2.054E-11	2.409E-11
3	4.359E+07	1.223E+08	3.88	1.412E-11	1.930E-11	1.992E-11	2.364E-11
4	4.217E+07	1.645E+08	5.21	1.327E-11	1.948E-11	2.161E-11	2.573E-11
5	4.459E+07	2.091E+08	6.63	1.233E-11	1.638E-11	1.695E-11	2.089E-11
6	4.593E+07	2.550E+08	8.08	1.225E-11	1.751E-11	1.857E-11	2.374E-11
Future	2.183E-08	4.734E+08	15	1.225E-11	1.751E-11	1.857E-11	2.374E-11
Future	3.156E+08	7.889E+08	25	1.225E-11	1.751E-11	1.857E-11	2.374E-11
Future	2.209E+08	1.010E+09	32	1.225E-11	1.751E-11	1.857E-11	2.374E-11
Future	1.262E+08	1.136E+09	36	1.225E-11	1.751E-11	1.857E-11	2.374E-11
Future	1.262E+08	1.262E+09	40	1.225E-11	1.751E-11	1.857E-11	2.374E-11
Future	2.525E+08	1.515E+09	48	1.225E-11	1.751E-11	1.857E-11	2.374E-11
Future	1.893E+08	1.704E+09	54	1.225E-11	1.751E-11	1.857E-11	2.374E-11
Future	1.893E+08	1.893E+09	60	1.225E-11	1.751E-11	1.857E-11	2.374E-11

Table 6-2 cont'd

Calculated Azimuthal Variation of Maximum Exposure Rates
And Integrated Exposures at the Reactor Vessel
Clad/Base Metal Interface

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Iron Atom Displacements [dpa]			
				0°	15°	30°	45°
1	3.800E+07	3.800E+07	1.20	7.426E-04	1.119E-03	1.128E-03	1.417E-03
2	4.073E+07	7.873E+07	2.49	1.236E-03	1.879E-03	1.928E-03	2.353E-03
3	4.359E+07	1.223E+08	3.88	1.850E-03	2.718E-03	2.794E-03	3.380E-03
4	4.217E+07	1.645E+08	5.21	2.400E-03	3.526E-03	3.690E-03	4.448E-03
5	4.459E+07	2.091E+08	6.63	2.944E-03	4.249E-03	4.437E-03	5.369E-03
6	4.593E+07	2.550E+08	8.08	3.506E-03	5.053E-03	5.290E-03	6.459E-03
Future	2.183E-08	4.734E+08	15	6.180E-03	8.876E-03	9.344E-03	1.164E-02
Future	3.156E+08	7.889E+08	25	1.005E-02	1.440E-02	1.521E-02	1.913E-02
Future	2.209E+08	1.010E+09	32	1.275E-02	1.827E-02	1.931E-02	2.438E-02
Future	1.262E+08	1.136E+09	36	1.430E-02	2.048E-02	2.165E-02	2.737E-02
Future	1.262E+08	1.262E+09	40	1.584E-02	2.269E-02	2.400E-02	3.037E-02
Future	2.525E+08	1.515E+09	48	1.894E-02	2.711E-02	2.868E-02	3.636E-02
Future	1.893E+08	1.704E+09	54	2.126E-02	3.043E-02	3.220E-02	4.086E-02
Future	1.893E+08	1.893E+09	60	2.358E-02	3.375E-02	3.572E-02	4.535E-02

Table 6-3

Relative Radial Distribution of Maximum Neutron Fluence (E > 1.0 MeV)
Within The Reactor Vessel Wall

RADIUS (cm)	AZIMUTHAL ANGLE			
	0°	15°	30°	45°
220.35	1.000	1.000	1.000	1.000
225.87	0.560	0.557	0.559	0.548
231.39	0.275	0.271	0.273	0.261
236.90	0.128	0.126	0.128	0.119
242.42	0.058	0.057	0.058	0.051
Note:	Base Metal Inner Radius = 220.35 cm Base Metal 1/4T = 225.87 cm Base Metal 1/2T = 231.39 cm Base Metal 3/4T = 236.90 cm Base Metal Outer Radius = 242.42 cm			

Note: Values for EOC 6

Table 6-4

Relative Radial Distribution of Maximum Iron Atom Displacements (dpa)
Within The Reactor Vessel Wall

RADIUS (cm)	AZIMUTHAL ANGLE			
	0°	15°	30°	45°
220.35	1.000	1.000	1.000	1.000
225.87	0.633	0.630	0.642	0.636
231.39	0.380	0.377	0.393	0.383
236.90	0.225	0.224	0.238	0.224
242.42	0.126	0.125	0.135	0.117
Note:	Base Metal Inner Radius = 220.35 cm Base Metal 1/4T = 225.87 cm Base Metal 1/2T = 231.39 cm Base Metal 3/4T = 236.90 cm Base Metal Outer Radius = 242.42 cm			

Note: Values for EOC 6

Table 6-5

Calculated Fast Neutron Exposure of Surveillance Capsules
Withdrawn from Watts Bar Unit 1

Capsule	Irradiation Time [EFPY]	Fluence (E > 1.0 MeV) [n/cm^2]	Iron Displacements [dpa]
U	1.20	4.47E+18	8.95E-03
W	3.88	1.08E+19	2.19E-02
X	6.63	1.71E+19	3.39E-02

Table 6-6

Calculated Surveillance Capsule Lead Factors

Capsule ID And Location	Status	Lead Factor
U (34° - dual)	Withdrawn EOC 1	5.00
W (34° - single)	Withdrawn EOC 3	5.05
X (34° - dual)	Withdrawn EOC 5	5.03
V (31.5° - dual)	In Reactor	4.31
Y (31.5° - dual)	In Reactor	4.31
Z (34° - single)	In Reactor	5.07

Note: Lead factors for capsules remaining in the reactor are based on cycle specific exposure calculations through the current operating fuel reload, i.e., Cycle 6.

7 SURVEILLANCE CAPSULE REMOVAL SCHEDULE

The following surveillance capsule removal schedule meets the requirements of ASTM E185-82 and is recommended for future capsules to be removed from the Watts Bar Unit 1 reactor vessel. This recommended removal schedule is applicable to 32 EFPY of operation.

Table 7-1 Recommended Surveillance Capsule Withdrawal Schedule

Capsule	Capsule Location	Lead Factor (a)	Withdrawal EFPY (b)	Fluence (n/cm^2) (a)
U	56°	5.0	1.20	4.47×10^{18} (c)
W	124°	5.05	3.88	1.08×10^{19} (c)
X	236°	5.03	6.63	1.71×10^{19} (c)
Z	304°	5.07	9.25	(d)
V	58.5°	4.31	Standby	(e)
Y	238.5°	4.31	Standby	(e)

Notes:
(a) Updated in Capsule X dosimetry analysis.
(b) Effective Full Power Years (EFPY) from plant startup.
(c) Plant specific evaluation.
(d) Capsule Z will have a fluence greater than one-times and less than two-times the peak EOL (32 EFPY vessel fluence (1.541 x 10^{19} n/cm^2). If Capsule Z is removed @ 9.25 EFPY it will also satisfy the last Capsule Removal for an EOL of 48 EFPY
(e) Section X1.M31, "Reactor Vessel Surveillance," of NUREG-1801 states that any surveillance capsules that are left in the reactor vessel should provide meaningful metallurgical data. The NRC specifically states that anything beyond 60 years of exposure is not meaningful metallurgical data. Hence, it is recommended that Capsules "V" and "Y" be removed at the closest outage on or after 10.7 EFPY (Equivalent to 1 times the 48 EFPY Peak Vessel Fluence of 2.298 x 10^{19} n/cm^2) and placed in storage.

8 REFERENCES

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23. RSIC Data Library Collection DLC-185, "BUGLE-96, Coupled 47 Neutron, 20 Gamma-Ray Group Cross Section Library Derived from ENDF/B-VI for LWR Shielding and Pressure Vessel Dosimetry Applications," March 1996.

APPENDIX A

VALIDATION OF THE RADIATION TRANSPORT MODELS BASED ON NEUTRON DOSIMETRY MEASUREMENTS

A.1 Neutron Dosimetry

Comparisons of measured dosimetry results to both the calculated and least squares adjusted values for all surveillance capsules withdrawn from service to date at Watts Bar Unit 1 are described herein. The sensor sets from these capsules have been analyzed in accordance with the current dosimetry evaluation methodology described in Regulatory Guide 1.190, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence."[A-1] One of the main purposes for presenting this material is to demonstrate that the overall measurements agree with the calculated and least squares adjusted values to within ± 20% as specified by Regulatory Guide 1.190, thus serving to validate the calculated neutron exposures previously reported in Section 6.2 of this report. This information may also be useful in the future, in particular, as least squares adjustment techniques become accepted in the regulatory environment.

A.1.1 Sensor Reaction Rate Determinations

In this section, the results of the evaluations of the four neutron sensor sets withdrawn to date as a part of the Watts Bar Unit 1 Reactor Vessel Materials Surveillance Program are presented. The capsule designation, location within the reactor, and time of withdrawal of each of these dosimetry sets were as follows:

Capsule ID	Azimuthal Location	Withdrawal Time	Irradiation Time [EFPY]
U	34°	End of Cycle 1	1.20
W	34°	End of Cycle 3	3.88
X	34°	End of Cycle 5	6.63

The azimuthal locations included in the above tabulation represent the first octant equivalent azimuthal angle of the geometric center of the respective surveillance capsules.

The passive neutron sensors included in the evaluations of Surveillance Capsules U, W, and X are summarized as follows:

Sensor Material	Reaction Of Interest	Capsule U	Capsule W	Capsule X
Copper	$^{63}Cu(n,\alpha)^{60}Co$	X	X	X
Iron	$^{54}Fe(n,p)^{54}Mn$	X	X	X
Nickel	$^{58}Ni(n,p)^{58}Co$	X	X	X
Uranium-238	$^{238}U(n,f)^{137}Cs$	X	X	X
Neptunium-237	$^{237}Np(n,f)^{137}Cs$	X	X	X
Cobalt-Aluminum*	$^{59}Co(n,\gamma)^{60}Co$	X	X	X

* The cobalt-aluminum measurements for this plant include both bare wire and cadmium-covered sensors.

Since all of the dosimetry monitors were accommodated within the dosimeter block centered at the radial, azimuthal, and axial center of the material test specimen array, gradient corrections were not required for these reaction rates. Pertinent physical and nuclear characteristics of the passive neutron sensors are listed in Table A-1.

The use of passive monitors such as those listed above does not yield a direct measure of the energy dependent neutron flux at the point of interest. Rather, the activation or fission process is a measure of the integrated effect that the time and energy dependent neutron flux has on the target material over the course of the irradiation period. An accurate assessment of the average neutron flux level incident on the various monitors may be derived from the activation measurements only if the irradiation parameters are well known. In particular, the following variables are of interest:

- The measured specific activity of each monitor,
- the physical characteristics of each monitor,
- the operating history of the reactor,
- the energy response of each monitor, and
- the neutron energy spectrum at the monitor location.

Results from the radiometric counting of the neutron sensors from Capsules U, W and X are documented in References A-2 through A-4, respectively. The radiometric counting of the sensors from Capsule X was carried out by Pace Analytical Services, Inc., located at the Westinghouse Waltz Mill Site. In all cases, the radiometric counting followed established ASTM procedures. Following sample preparation and weighing, the specific activity of each sensor was determined by means of a high-resolution gamma spectrometer. For the copper, iron, nickel, and cobalt-aluminum sensors, these analyses were performed by direct counting of each of the individual samples. In the case of the uranium and neptunium fission sensors, the analyses were carried out by direct counting preceded by dissolution and chemical separation of cesium from the sensor material.

The irradiation history of the reactor over the irradiation periods experienced by Capsules U, W, and X was based on the reported monthly power generation of Watts Bar Unit 1 from initial reactor criticality through the end of the dosimetry evaluation period. For the sensor sets utilized in the surveillance capsules, the half-lives of the product isotopes are long enough that a monthly histogram describing reactor operation has proven to be an adequate representation for use in radioactive decay corrections for the reactions of interest in the exposure evaluations. The irradiation history applicable to Capsules U, W, and X is given in Table A-2.

Having the measured specific activities, the physical characteristics of the sensors, and the operating history of the reactor, reaction rates referenced to full-power operation were determined from the following equation:

$$R = \frac{A}{N_0\,F\,Y \sum \frac{P_j}{P_{ref}}\,C_j\,[1-e^{-\lambda t_j}]\,[e^{-\lambda t_d}]}$$

where:

R = Reaction rate averaged over the irradiation period and referenced to operation at a core power level of P_{ref} (rps/nucleus).

A = Measured specific activity (dps/gm).

N_0 = Number of target element atoms per gram of sensor.

F = Weight fraction of the target isotope in the sensor material.

Y = Number of product atoms produced per reaction.

P_j = Average core power level during irradiation period j (MW).

P_{ref} = Maximum or reference power level of the reactor (MW).

C_j = Calculated ratio of ϕ(E > 1.0 MeV) during irradiation period j to the time weighted average ϕ(E > 1.0 MeV) over the entire irradiation period.

λ = Decay constant of the product isotope (1/sec).

t_j = Length of irradiation period j (sec).

t_d = Decay time following irradiation period j (sec).

and the summation is carried out over the total number of monthly intervals comprising the irradiation period.

In the equation describing the reaction rate calculation, the ratio $[P_j]/[P_{ref}]$ accounts for month-by-month variation of reactor core power level within any given fuel cycle as well as over multiple fuel cycles. The ratio C_j, which was calculated for each fuel cycle using the transport methodology discussed in Section 6.2, accounts for the change in sensor reaction rates caused by variations in flux level induced by changes in core spatial power distributions from fuel cycle to fuel cycle. For a single-cycle irradiation, C_j is normally taken to be 1.0. However, for multiple-cycle irradiations, particularly those employing low leakage fuel management, the additional C_j term should be employed. The impact of changing flux levels for constant power operation can be quite significant for sensor sets that have been irradiated for many cycles in a reactor that has transitioned from non-low leakage to low leakage fuel management or for sensor sets contained in surveillance capsules that have been moved from one capsule location to another. The fuel cycle specific neutron flux values along with the computed values for C_j are listed in Table A-3. These flux values represent the cycle dependent results at the radial and azimuthal center of the respective capsules at the axial elevation of the active fuel midplane.

Prior to using the measured reaction rates in the least-squares evaluations of the dosimetry sensor sets, additional corrections were made to the ^{238}U measurements to account for the presence of ^{235}U impurities in the sensors as well as to adjust for the build-in of plutonium isotopes over the course of the irradiation. Corrections were also made to the ^{238}U and ^{237}Np sensor reaction rates to account for gamma ray induced fission reactions that occurred over the course of the capsule irradiations. The correction factors applied to the Watts Bar Unit 1 fission sensor reaction rates are summarized as follows:

Correction	Capsule U	Capsule W	Capsule X
^{235}U Impurity/Pu Build-in	0.867	0.843	0.819
$^{238}U(\gamma,f)$	0.964	0.964	0.964
Net ^{238}U Correction	0.836	0.813	0.789
$^{237}Np(\gamma,f)$	0.990	0.990	0.990

These factors were applied in a multiplicative fashion to the decay corrected uranium and neptunium fission sensor reaction rates.

Results of the sensor reaction rate determinations for Capsules U, W, and X are given in Table A-4. In Table A-4, the measured specific activities, decay corrected saturated specific activities, and computed reaction rates for each sensor indexed to the radial center of the capsule are listed. The fission sensor reaction rates are listed both with and without the applied corrections for ^{238}U impurities, plutonium build-in, and gamma ray induced fission effects.

A.1.2 Least Squares Evaluation of Sensor Sets

Least squares adjustment methods provide the capability of combining the measurement data with the corresponding neutron transport calculations resulting in a Best Estimate neutron energy spectrum with associated uncertainties. Best Estimates for key exposure parameters such as $\phi(E > 1.0\ MeV)$ or dpa/s along with their uncertainties are then easily obtained from the adjusted spectrum. In general, the least squares methods, as applied to surveillance capsule dosimetry evaluations, act to reconcile the measured sensor reaction rate data, dosimetry reaction cross-sections, and the calculated neutron energy spectrum within their respective uncertainties. For example,

$$R_i \pm \delta_{R_i} = \sum_g (\sigma_{ig} \pm \delta_{\sigma_{ig}})(\phi_g \pm \delta_{\phi_g})$$

relates a set of measured reaction rates, R_i, to a single neutron spectrum, ϕ_g, through the multigroup dosimeter reaction cross-section, σ_{ig}, each with an uncertainty δ. The primary objective of the least squares evaluation is to produce unbiased estimates of the neutron exposure parameters at the location of the measurement.

For the least squares evaluation of the Watts Bar Unit 1 surveillance capsule dosimetry, the FERRET code[A-4] was employed to combine the results of the plant specific neutron transport calculations and sensor set reaction rate measurements to determine best-estimate values of exposure parameters ($\phi(E > 1.0\ MeV)$ and dpa) along with associated uncertainties for the five in-vessel capsules withdrawn to date.

The application of the least squares methodology requires the following input:

1 - The calculated neutron energy spectrum and associated uncertainties at the measurement location.

2 - The measured reaction rates and associated uncertainty for each sensor contained in the multiple foil set.

3 - The energy dependent dosimetry reaction cross-sections and associated uncertainties for each sensor contained in the multiple foil sensor set.

For the Watts Bar Unit 1 application, the calculated neutron spectrum was obtained from the results of plant specific neutron transport calculations described in Section 6.2 of this report. The sensor reaction rates were derived from the measured specific activities using the procedures described in Section A.1.1. The dosimetry reaction cross-sections and uncertainties were obtained from the SNLRML dosimetry cross-section library[A-5]. The SNLRML library is an evaluated dosimetry reaction cross-section compilation recommended for use in LWR evaluations by ASTM Standard E1018, "Application of ASTM Evaluated Cross-Section Data File, Matrix E 706 (IIB)".

The uncertainties associated with the measured reaction rates, dosimetry cross-sections, and calculated neutron spectrum were input to the least squares procedure in the form of variances and covariances. The assignment of the input uncertainties followed the guidance provided in ASTM Standard E 944, "Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance."

The following provides a summary of the uncertainties associated with the least squares evaluation of the Watts Bar Unit 1 surveillance capsule sensor sets.

Reaction Rate Uncertainties

The overall uncertainty associated with the measured reaction rates includes components due to the basic measurement process, irradiation history corrections, and corrections for competing reactions. A high level of accuracy in the reaction rate determinations is assured by utilizing laboratory procedures that conform to the ASTM National Consensus Standards for reaction rate determinations for each sensor type.

After combining all of these uncertainty components, the sensor reaction rates derived from the counting and data evaluation procedures were assigned the following net uncertainties for input to the least squares evaluation:

Reaction	Uncertainty
$^{63}Cu(n,\alpha)^{60}Co$	5%
$^{54}Fe(n,p)^{54}Mn$	5%
$^{58}Ni(n,p)^{58}Co$	5%
$^{238}U(n,f)^{137}Cs$	10%
$^{237}Np(n,f)^{137}Cs$	10%
$^{59}Co(n,\gamma)^{60}Co$	5%

These uncertainties are given at the 1σ level.

Dosimetry Cross-Section Uncertainties

The reaction rate cross-sections used in the least squares evaluations were taken from the SNLRML library. This data library provides reaction cross-sections and associated uncertainties, including covariances, for 66 dosimetry sensors in common use. Both cross-sections and uncertainties are provided in a fine multigroup structure for use in least squares adjustment applications. These cross-sections were compiled from the most recent cross-section evaluations and they have been tested with respect to their accuracy and consistency for least squares evaluations. Further, the library has been empirically tested for use in fission spectra determination as well as in the fluence and energy characterization of 14 MeV neutron sources.

For sensors included in the Farley Unit 1 surveillance program, the following uncertainties in the fission spectrum averaged cross-sections are provided in the SNLRML documentation package.

Reaction	Uncertainty
$^{63}Cu(n,\alpha)^{60}Co$	4.08-4.16%
$^{54}Fe(n,p)^{54}Mn$	3.05-3.11%
$^{58}Ni(n,p)^{58}Co$	4.49-4.56%
$^{238}U(n,f)^{137}Cs$	0.54-0.64%
$^{237}Np(n,f)^{137}Cs$	10.32-10.97%
$^{59}Co(n,\gamma)^{60}Co$	0.79-3.59%

These tabulated ranges provide an indication of the dosimetry cross-section uncertainties associated with the sensor sets used in LWR irradiations.

Calculated Neutron Spectrum

The neutron spectra input to the least squares adjustment procedure were obtained directly from the results of plant specific transport calculations for each surveillance capsule irradiation period and location. The spectrum for each capsule was input in an absolute sense (rather than as simply a relative spectral shape). Therefore, within the constraints of the assigned uncertainties, the calculated data were treated equally with the measurements.

While the uncertainties associated with the reaction rates were obtained from the measurement procedures and counting benchmarks and the dosimetry cross-section uncertainties were supplied directly with the SNLRML library, the uncertainty matrix for the calculated spectrum was constructed from the following relationship:

$$M_{gg'} = R_n^2 + R_g * R_{g'} * P_{gg'}$$

where R_n specifies an overall fractional normalization uncertainty and the fractional uncertainties R_g and $R_{g'}$ specify additional random groupwise uncertainties that are correlated with a correlation matrix given by:

$$P_{gg'} = [1-\theta]\delta_{gg'} + \theta\, e^{-H}$$

where

$$H = \frac{(g-g')^2}{2\gamma^2}$$

The first term in the correlation matrix equation specifies purely random uncertainties, while the second term describes the short-range correlations over a group range γ (θ specifies the strength of the latter term). The value of δ is 1.0 when $g = g'$, and is 0.0 otherwise.

The set of parameters defining the input covariance matrix for the Farley Unit 1 calculated spectra was as follows:

Flux Normalization Uncertainty (R_n)	15%
Flux Group Uncertainties (R_g, $R_{g'}$)	
($E > 0.0055$ MeV)	15%
(0.68 eV $< E <$ 0.0055 MeV)	29%
($E < 0.68$ eV)	52%
Short Range Correlation (θ)	
($E > 0.0055$ MeV)	0.9
(0.68 eV $< E <$ 0.0055 MeV)	0.5
($E < 0.68$ eV)	0.5
Flux Group Correlation Range (γ)	
($E > 0.0055$ MeV)	6
(0.68 eV $< E <$ 0.0055 MeV)	3
($E < 0.68$ eV)	2

A.1.3 Comparisons of Measurements and Calculations

Results of the least squares evaluations of the dosimetry from the Watts Bar Unit 1 surveillance capsules withdrawn to date are provided in Tables A-5 and A-6. In Table A-5, measured, calculated, and best-estimate values for sensor reaction rates are given for each capsule. Also provided in this tabulation are ratios of the measured reaction rates to both the calculated and least squares adjusted reaction rates. These ratios of M/C and M/BE illustrate the consistency of the fit of the calculated neutron energy spectra to the measured reaction rates both before and after adjustment. In Table A-6, comparison of the calculated and best estimate values of neutron flux ($E > 1.0$ MeV) and iron atom displacement rate are tabulated along with the BE/C ratios observed for each of the capsules.

The data comparisons provided in Tables A-5 and A-6 show that the adjustments to the calculated spectra are relatively small and well within the assigned uncertainties for the calculated spectra, measured sensor reaction rates, and dosimetry reaction cross-sections. Further, these results indicate that the use of the least squares evaluation results in a reduction in the uncertainties associated with the exposure of the surveillance capsules. From Section 6.4 of this report, it may be noted that the uncertainty associated with the unadjusted calculation of neutron fluence ($E > 1.0$ MeV) and iron atom displacements at the surveillance capsule locations is specified as 12% at the 1σ level. From Table A-6, it is noted that the corresponding uncertainties associated with the least squares adjusted exposure parameters have been reduced to 7% for neutron flux ($E > 1.0$ MeV) and 11% for iron atom displacement rate. Again, the uncertainties from the least squares evaluation are at the 1σ level.

Further comparisons of the measurement results with calculations are given in Tables A-7 and A-8. These comparisons are given on two levels. In Table A-7, calculations of individual threshold sensor reaction rates are compared directly with the corresponding measurements. These threshold reaction rate comparisons provide a good evaluation of the accuracy of the fast neutron portion of the calculated energy spectra. In Table A-8, calculations of fast neutron exposure rates in terms of $\phi(E > 1.0 \text{ MeV})$ and dpa/s are compared with the best estimate results obtained from the least squares evaluation of the capsule dosimetry results. These two levels of comparison yield consistent and similar results with all measurement-to-calculation comparisons falling well within the 20% limits specified as the acceptance criteria in Regulatory Guide 1.190.

In the case of the direct comparison of measured and calculated sensor reaction rates, the M/C comparisons for fast neutron reactions range from 0.92–1.29 for the 15 samples included in the data set. The overall average M/C ratio for the entire set of Watts Bar Unit 1 data is 1.08 with an associated standard deviation of 5.8%.

In the comparisons of best estimate and calculated fast neutron exposure parameters, the corresponding BE/C comparisons for the capsule data sets range from 0.98–1.15 for neutron flux (E > 1.0 MeV) and from 1.00 to 1.18 for iron atom displacement rate. The overall average BE/C ratios for neutron flux (E > 1.0 MeV) and iron atom displacement rate are 1.06 with a standard deviation of 8.2% and 1.09 with a standard deviation of 9.1%, respectively.

Based on these comparisons, it is concluded that the calculated fast neutron exposures provided in Section 6.2 of this report are validated for use in the assessment of the condition of the materials comprising the beltline region of the Watts Bar Unit 1 reactor pressure vessel.

Table A-1

Nuclear Parameters Used In The Evaluation Of Neutron Sensors

Monitor Material	Reaction of Interest	Target Atom Fraction	90% Response Range (MeV)	Product Half-life	Fission Yield (%)
Copper	$^{63}Cu\ (n,\alpha)$	0.6917	4.9 – 11.8	5.271 y	
Iron	$^{54}Fe\ (n,p)$	0.0585	2.1 – 8.4	312.1 d	
Nickel	$^{58}Ni\ (n,p)$	0.6808	1.5 – 8.2	70.82 d	
Uranium-238	$^{238}U\ (n,f)$	1.0000	1.2 – 6.8	30.07 y	6.02
Neptunium-237	$^{237}Np\ (n,f)$	1.0000	0.4 – 3.6	30.07 y	6.17
Cobalt-Aluminum	$^{59}Co\ (n,\gamma)$	0.0015	non-threshold	5.271 y	

Note: The 90% response range is defined such that, in the neutron spectrum characteristic of the Watts Bar Unit 1 surveillance capsules, approximately 90% of the sensor response is due to neutrons in the energy range specified with approximately 5% of the total response due to neutrons with energies below the lower limit and 5% of the total response due to neutrons with energies above the upper limit.

Table A-2

Monthly Thermal Generation During The First Five Fuel Cycles
Of The Watts Bar Unit 1 Reactor
(Reactor Power of 3411 MWt for Cycles 1 through middle of Cycle 4,
and 3459MW for subsequent cycles)

Cycle 1		Cycle 2		Cycle 3	
Month	Thermal Generation [MW-Hr]	Month	Thermal Generation [MW-Hr]	Month	Thermal Generation [MW-Hr]
Jan-96	9519	Oct-97	709914	Apr-99	1068631
Feb-96	49773	Nov-97	2449654	May-99	2454763
Mar-96	475248	Dec-97	2527971	Jun-99	2454685
Apr-96	999029	Jan-98	2523492	Jul-99	2536887
May-96	1713718	Feb-98	2142012	Aug-99	2526645
Jun-96	2348718	Mar-98	2180599	Sep-99	2455157
Jul-96	2523691	Apr-98	2370444	Oct-99	2540350
Aug-96	2525629	May-98	2535488	Nov-99	2454874
Sep-96	2184725	Jun-98	2445551	Dec-99	2536956
Oct-96	1114619	Jul-98	2531951	Jan-00	2536601
Nov-96	2202224	Aug-98	2486237	Feb-00	2373327
Dec-96	2523130	Sep-98	2429447	Mar-00	2536915
Jan-97	1956638	Oct-98	2470835	Apr-00	2451520
Feb-97	2147746	Nov-98	2452741	May-00	2536436
Mar-97	1645462	Dec-98	2535907	Jun-00	2455171
Apr-97	2236507	Jan-99	2280206	Jul-00	2534880
May-97	2519097	Feb-99	1519605	Aug-00	2279989
Jun-97	2237128	Mar-99	0	Sep-00	570521
Jul-97	2399891				
Aug-97	1934439				
Sep-97	262258				
Total	36009189	Total	38592054	Total	41304308
[EFPS]	3.800E+07	[EFPS]	4.073E+07	[EFPS]	4.359E+07
[EFPY]	1.204	[EFPY]	1.291	[EFPY]	1.381
To Date		To Date		To Date	
[EFPS]	3.800E+07	[EFPS]	7.873E+07	[EFPS]	1.223E+08
[EFPY]	1.204	[EFPY]	2.495	[EFPY]	3.876

Table A-2 (continued)

Monthly Thermal Generation During The First Five Fuel Cycles
Of The Watts Bar Unit 1 Reactor
(Reactor Power of 3411 MWt for Cycles 1 through middle of Cycle 4,
and 3459MW for subsequent cycles)

Cycle 4		Cycle 5	
Month	Thermal Generation [MW-Hr]	Month	Thermal Generation [MW-Hr]
Oct-00	1906668	Mar-02	759955
Nov-00	2455222	Apr-02	2486032
Dec-00	2536907	May-02	2041632
Jan-01	2539043	Jun-02	2489640
Feb-01	2323719	Jul-02	2440231
Mar-01	2571100	Aug-02	2572406
Apr-01	2486145	Sep-02	2489113
May-01	2572676	Oct-02	2573865
Jun-01	2384162	Nov-02	2489493
Jul-01	1723109	Dec-02	2547822
Aug-01	2572727	Jan-03	2572408
Sep-01	2298210	Feb-03	2322599
Oct-01	2576028	Mar-03	2052502
Nov-01	2489629	Apr-03	2485939
Dec-01	2423020	May-03	2572277
Jan-02	2572218	Jun-03	2487655
Feb-02	1970262	Jul-03	2570050
		Aug-03	2409124
		Sep-03	485359
Total	40400845	Total	42848102
[EFPS]	4.217E+07	[EFPS]	4.459E+07
[EFPY]	1.336	[EFPY]	1.413
To Date		To Date	
[EFPS]	1.645E+08	[EFPS]	2.091E+08
[EFPY]	5.213	[EFPY]	6.626

Table A-3

Calculated C_j Factors at the Surveillance Capsule Center
Core Midplane Elevation

Fuel Cycle	ϕ(E > 1.0 MeV) [n/cm^2-s]		
	Capsule U	Capsule W	Capsule X
1	1.176E+11	1.194E+11	1.176E+11
2		7.444E+10	7.339E+10
3		7.389E+10	7.284E+10
4			8.363E+10
5			6.520E+10
Average	1.176E+11	8.821E+10	8.163E+10

Table A-4

Measured Sensor Activities And Reaction Rates

Watts Bar Unit 1 - Surveillance Capsule U

Location	Target Isotope	Product Isotope	Measured Actitivy (dps/g)	Saturated Actitivy (dps/g)	Reaction Rate (rps/atom)	Averaged Reaction Rate (rps/atom)	Corrected Averaged Reaction Rate (rps/atom)
Top	Cu-63	Co-60	5.05E+04	3.684E+05	5.620E-17		
Middle	Cu-63	Co-60	5.34E+04	3.895E+05	5.942E-17		
Bottom	Cu-63	Co-60	5.25E+04	3.829E+05	5.842E-17	5.801E-17	5.801E-17
Top	Fe-54	Mn-54	1.62E+06	3.855E+06	6.111E-15		
Middle	Fe-54	Mn-54	1.71E+06	4.069E+06	6.450E-15		
Bottom	Fe-54	Mn-54	1.71E+06	4.069E+06	6.450E-15	6.337E-15	6.337E-15
Top	Ni-58	Co-58	1.20E+07	5.968E+07	8.544E-15		
Middle	Ni-58	Co-58	1.25E+07	6.217E+07	8.900E-15		
Bottom	Ni-58	Co-58	1.26E+07	6.267E+07	8.971E-15	8.805E-15	8.805E-15
Top	Co-59	Co-60	1.55E+07	1.131E+08	7.376E-12		
Top	Co-59	Co-60	1.28E+07	9.337E+07	6.091E-12		
Middle	Co-59	Co-60	1.43E+07	1.043E+08	6.805E-12		
Middle	Co-59	Co-60	1.19E+07	8.680E+07	5.663E-12		
Bottom	Co-59	Co-60	1.41E+07	1.028E+08	6.710E-12		
Bottom	Co-59	Co-60	1.22E+07	8.899E+07	5.806E-12	6.409E-12	6.409E-12
Top	Co-59 Cd	Co-60	7.59E+06	5.536E+07	3.612E-12		
Middle	Co-59 Cd	Co-60	7.06E+06	5.150E+07	3.360E-12		
Bottom	Co-59 Cd	Co-60	7.10E+06	5.179E+07	3.379E-12	3.450E-12	3.450E-12
	U-238	Cs-137	2.34E+05	8.647E+06	5.678E-14	5.678E-14	4.744E-14
	Np-237	Cs-137	1.94E+06	7.169E+07	4.574E-13	4.574E-13	4.528E-13

Notes: 1) Measured specific activities are indexed to a counting date of January 30, 1998.
2) The average ^{238}U (n,f) reaction rate of 4.744E-14 includes a correction factor of 0.867 to account for plutonium build-in and an additional factor of 0.964 to account for photo-fission effects in the sensor.
3) The average ^{237}Np (n,f) reaction rate of 4.528E-13 includes a correction factor of 0.990 to account for photo-fission effects in the sensor.

Table A-4 cont'd

Measured Sensor Activities And Reaction Rates

Watts Bar Unit 1 - Surveillance Capsule W

Location	Target Isotope	Product Isotope	Measured Actitivy (micro-Ci/g)	Measured Actitivy (dps/g)	Saturated Actitivy (dps/g)	Reaction Rate (rps/atom)	Averaged Reaction Rate (rps/atom)	Corrected Averaged Reaction Rate (rps/atom)
Top	Cu-63	Co-60	4.975	1.84E+05	4.874E+05	5.143E-17		
Middle	Cu-63	Co-60	5.265	1.95E+05	5.166E+05	5.451E-17		
Bottom	Cu-63	Co-60	5.232	1.94E+05	5.139E+05	5.423E-17	5.339E-17	5.339E-17
Top	Fe-54	Mn-54	1251	4.63E+07	5.950E+07	5.519E-15		
Middle	Fe-54	Mn-54	1308	4.84E+07	6.220E+07	5.769E-15		
Bottom	Fe-54	Mn-54	1269	4.70E+07	6.040E+07	5.602E-15	5.630E-15	5.630E-15
Top	Ni-58	Co-58	1664	6.16E+07	7.787E+07	7.592E-15		
Middle	Ni-58	Co-58	1713	6.34E+07	8.015E+07	7.814E-15		
Bottom	Ni-58	Co-58	1665	6.16E+07	7.787E+07	7.592E-15	7.666E-15	7.666E-15
Top	Co-59	Co-60	5.483E+05	2.03E+10	5.378E+10	5.262E-12		
Top	Co-59	Co-60	4.803E+05	1.78E+10	4.715E+10	4.614E-12		
Middle	Co-59	Co-60	5.070E+05	1.88E+10	4.980E+10	4.874E-12		
Middle	Co-59	Co-60	4.191E+05	1.55E+10	4.106E+10	4.018E-12		
Bottom	Co-59	Co-60	5.247E+05	1.94E+10	5.139E+10	5.029E-12		
Bottom	Co-59	Co-60	4.432E+05	1.64E+10	4.344E+10	4.251E-12	4.675E-12	4.675E-12
Top	Co-59 Cd	Co-60	2.740E+05	1.01E+10	2.676E+10	2.618E-12		
Middle	Co-59 Cd	Co-60	2.616E+05	9.68E+09	2.564E+10	2.509E-12		
Bottom	Co-59 Cd	Co-60	2.690E+05	9.95E+09	2.636E+10	2.579E-12	2.569E-12	2.569E-12
	U-238	Cs-137	9.13	3.97E+05	4.694E+06	3.082E-14	3.082E-14	2.504E-14
	Np-237	Cs-137	124.8	4.62E+06	5.462E+07	3.485E-13	3.485E-13	3.450E-13

Notes: 1) Measured specific activities are indexed to a counting date of September 10, 2000.
2) The average ^{238}U (n,f) reaction rate of 2.504E-14 includes a correction factor of 0.843 to account for plutonium build-in and an additional factor of 0.964 to account for photo-fission effects in the sensor.
3) The average ^{237}Np (n,f) reaction rate of 3.450E-13 includes a correction factor of 0.990 to account for photo-fission effects in the sensor.

Table A-4 cont'd

Measured Sensor Activities And Reaction Rates

Watts Bar Unit 1 - Surveillance Capsule X

Location	Target Isotope	Product Isotope	Measured Actitivy (dps/g)	Saturated Actitivy (dps/g)	Reaction Rate (rps/atom)	Averaged Reaction Rate (rps/atom)	Corrected Averaged Reaction Rate (rps/atom)
Top	Cu-63	Co-60	1.52E+05	2.889E+05	4.408E-17		
Middle	Cu-63	Co-60	1.55E+05	2.946E+05	4.495E-17		
Bottom	Cu-63	Co-60	1.56E+05	2.965E+05	4.524E-17	4.476E-17	4.476E-17
Top	Fe-54	Mn-54	1.84E+06	2.723E+06	4.316E-15		
Middle	Fe-54	Mn-54	1.96E+06	2.900E+06	4.597E-15		
Bottom	Fe-54	Mn-54	1.90E+06	2.811E+06	4.456E-15	4.456E-15	4.456E-15
Top	Ni-58	Co-58	1.59E+07	4.495E+07	6.436E-15		
Middle	Ni-58	Co-58	1.68E+07	4.750E+07	6.800E-15		
Bottom	Ni-58	Co-58	1.69E+07	4.778E+07	6.840E-15	6.692E-15	6.692E-15
Top	Co-59	Co-60	3.13E+07	5.950E+07	3.882E-12		
Top	Co-59	Co-60	3.54E+07	6.729E+07	4.390E-12		
Middle	Co-59	Co-60	3.35E+07	6.748E+07	4.403E-12		
Middle	Co-59	Co-60	2.75E+07	5.228E+07	3.411E-12		
Bottom	Co-59	Co-60	2.93E+07	5.570E+07	3.634E-12		
Bottom	Co-59	Co-60	3.41E+07	6.482E+07	4.229E-12	3.991E-12	3.991E-12
Top	Co-59 Cd	Co-60	1.87E+07	3.555E+07	2.319E-12		
Middle	Co-59 Cd	Co-60	1.79E+07	3.403E+07	2.220E-12	2.270E-12	2.270E-12
Bottom	Co-59 Cd	Co-60	---				
	U-238	Cs-137	6.61E+05	4.759E+06	3.125E-14	3.125E-14	2.467E-14
	Np-237	Cs-137	5.82E+06	4.190E+07	2.673E-13	2.673E-13	2.646E-13

Notes: 1) Measured specific activities are indexed to a counting date of November 26, 2003.

2) The average ^{238}U (n,f) reaction rate of 2.467E-14 includes a correction factor of 0.819 to account for plutonium build-in and an additional factor of 0.964 to account for photo-fission effects in the sensor.

3) The average ^{237}Np (n,f) reaction rate of 2.646E-13 includes a correction factor of 0.990 to account for photo-fission effects in the sensor.

Table A-5

Comparison of Measured, Calculated, and Best Estimate
Reaction Rates At The Surveillance Capsule Center

Capsule U

	Reaction Rate [rps/atom]				
Reaction	Measured	Calculated	Best Estimate	M/C	M/BE
$^{63}Cu(n,\alpha)^{60}Co$	5.80E-17	5.45E-17	5.65E-17	1.06	1.03
$^{54}Fe(n,p)^{54}Mn$	6.34E-15	6.48E-15	6.50E-15	0.98	0.97
$^{58}Ni(n,p)^{58}Co$	8.81E-15	9.18E-15	9.24E-15	0.96	0.95
$^{238}U(n,f)^{137}Cs$ (Cd)	4.74E-14	3.66E-14	3.99E-14	1.29	1.19
$^{237}Np(n,f)^{137}Cs$ (Cd)	4.53E-13	3.76E-13	4.49E-13	1.20	1.01
$^{59}Co(n,\gamma)^{60}Co$	6.41E-12	5.58E-12	6.38E-12	1.15	1.00
$^{59}Co(n,\gamma)^{60}Co$ (Cd)	3.45E-12	3.90E-12	3.47E-12	0.89	1.00

Capsule W

	Reaction Rate [rps/atom]				
Reaction	Measured	Calculated	Best Estimate	M/C	M/BE
$^{63}Cu(n,\alpha)^{60}Co$	5.34E-17	4.20E-17	5.28E-17	1.27	1.01
$^{54}Fe(n,p)^{54}Mn$	5.63E-15	4.86E-15	5.54E-15	1.16	1.02
$^{58}Ni(n,p)^{58}Co$	7.67E-15	6.88E-15	7.70E-15	1.12	1.00
$^{238}U(n,f)^{137}Cs$ (Cd)	2.50E-14	2.73E-14	2.90E-14	0.92	0.86
$^{237}Np(n,f)^{137}Cs$ (Cd)	3.45E-13	2.85E-13	3.24E-13	1.21	1.06
$^{59}Co(n,\gamma)^{60}Co$	4.67E-12	3.80E-12	4.65E-12	1.23	1.01
$^{59}Co(n,\gamma)^{60}Co$ (Cd)	2.57E-12	2.75E-12	2.58E-12	0.93	0.99

Capsule X

	Reaction Rate [rps/atom]				
Reaction	Measured	Calculated	Best Estimate	M/C	M/BE
$^{63}Cu(n,\alpha)^{60}Co$	4.48E-07	4.07E-17	4.41E-17	1.10	1.02
$^{54}Fe(n,p)^{54}Mn$	4.46E-15	4.65E-15	4.61E-15	0.96	0.97
$^{58}Ni(n,p)^{58}Co$	6.69E-15	6.55E-15	6.58E-15	1.02	1.02
$^{238}U(n,f)^{137}Cs$ (Cd)	1.47E-14	2.57E-14	2.50E-14	0.96	0.99
$^{237}Np(n,f)^{137}Cs$ (Cd)	2.65E-13	2.59E-13	2.60E-13	1.02	1.02
$^{59}Co(n,\gamma)^{60}Co$	3.99E-12	2.72E-12	3.98E-12	1.06	1.00
$^{59}Co(n,\gamma)^{60}Co$ (Cd)	2.27E-12	2.63E-12	2.28E-12	0.86	1.00

Table A-6

Comparison of Calculated and Best Estimate Exposure Rates
at the Surveillance Capsule Center

Capsule ID	$\phi(E > 1.0\ MeV)\ [n/cm^2\text{-}s]$			
	Calculated	Best Estimate	Uncertainty (1σ)	BE/C
U	1.075E+11	1.35e+11	7	1.15
W	8.821E+10	9.35E+10	7	1.06
X	8.164E+10	8.02E+10	7	0.98

Note: Calculated results are based on the synthesized transport calculations taken at the core midplane following the completion of each respective capsules irradiation period.

Capsule ID	Iron Atom Displacement Rate [dpa/s]			
	Calculated	Best Estimate	Uncertainty (1σ)	BE/C
U	2.35E-10	2.78E-10	11	1.18
W	1.79E-10	1.96E-10	11	1.10
X	1.62E-10	1.62E-10	11	1.00

Note: Calculated results are based on the synthesized transport calculations taken at the core midplane following the completion of each respective capsules irradiation period.

Table A-7

Comparison of Measured/Calculated (M/C) Sensor Reaction Rate Ratios Including all Fast Neutron Threshold Reactions

Reaction	M/C Ratio		
	Capsule U	Capsule W	Capsule X
$^{63}Cu(n,\alpha)^{60}Co$	1.06	1.27	1.10
$^{54}Fe(n,p)^{54}Mn$	0.98	1.16	0.96
$^{58}Ni(n,p)^{58}Co$	0.96	1.12	1.02
$^{238}U(n,p)^{137}Cs$ (Cd)	1.29	0.92	0.92
$^{237}Np(n,f)^{137}Cs$ (Cd)	1.20	1.21	1.02
Average	1.10	1.14	1.01
% Standard Deviation	14	13	6

Note: The overall average M/C ratio for the set of 15 sensor measurements is 1.08 with an associated standard deviation of 11%.

Table A-8

Comparison of Best Estimate/Calculated (BE/C) Exposure Rate Ratios

Capsule ID	BE/C Ratio	
	$\phi(E > 1.0\ MeV)$	dpa/s
U	1.13	1.15
W	1.05	1.06
X	0.97	0.98
Average	1.05	1.06
% Standard Deviation	8.1	8.2

Appendix A References

A-1. Regulatory Guide RG-1.190, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence," U. S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, March 2001.

A-2. "Dosimetry Characterization; Purchase Order No. WGYP-7500 - Watts Bar Dosimetry; WATTS BAR; Energy Center Antech Ltd. Project No. 98-0027W", Antech Ltd., February 10, 1998.

A-3. "Analysis of Capsule W from the Tennessee Valley Authority Watts Bar Unit 1 Reactor Vessel Material Surveillance Program", BWXT Services, Inc., September 10, 2001.

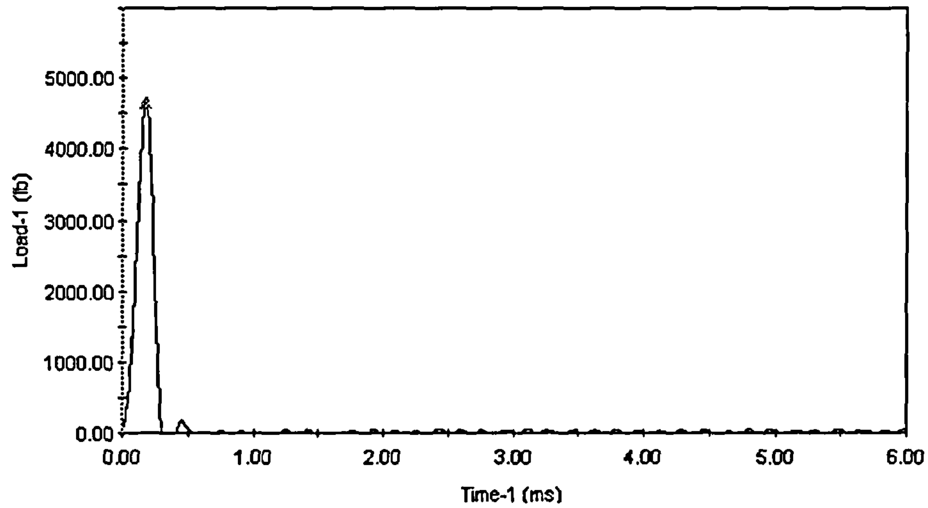
A-4. A. Schmittroth, *FERRET Data Analysis Core*, HEDL-TME 79-40, Hanford Engineering Development Laboratory, Richland, WA, September 1979.

A-5. RSIC Data Library Collection DLC-178, "SNLRML Recommended Dosimetry Cross-Section Compendium", July 1994..

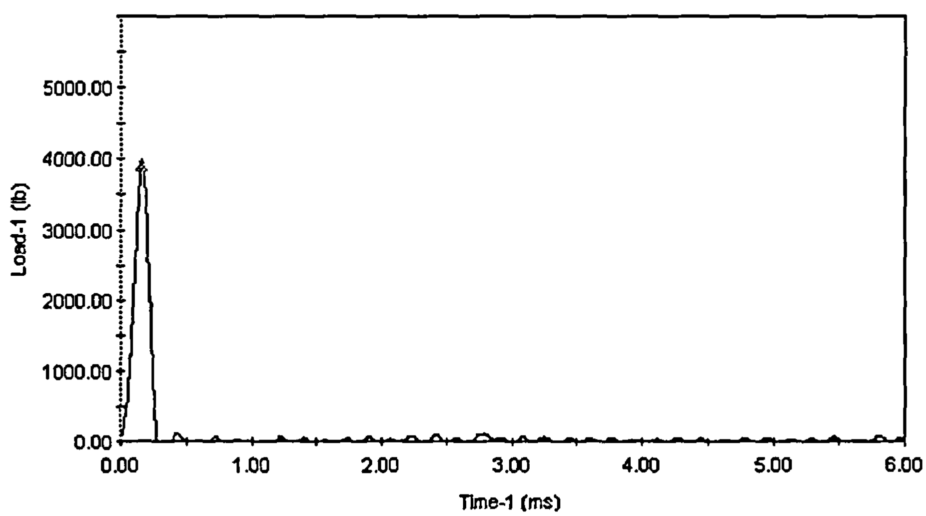
APPENDIX B

LOAD-TIME RECORDS FOR CHARPY SPECIMEN TESTS

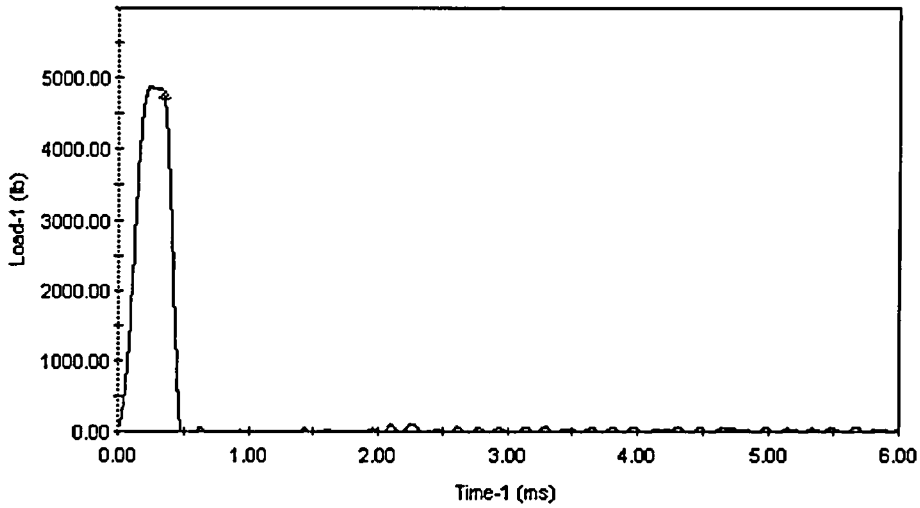
- Specimen prefix "WL" denotes Lower Plate, Longitudinal Orientation
- Specimen prefix "WT" denotes Lower Plate, Transverse Orientation
- Specimen prefix "WW" denotes Weld Material
- Specimen prefix "WH" denotes Heat-Affected Zone material
- Load (1) is in units of lbs
- Time (1) is in units of milli seconds



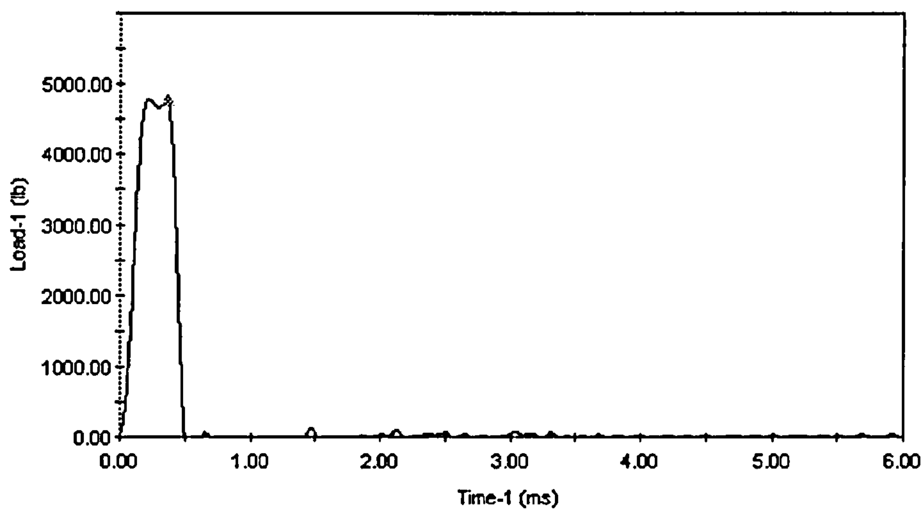
WL55, -75°F



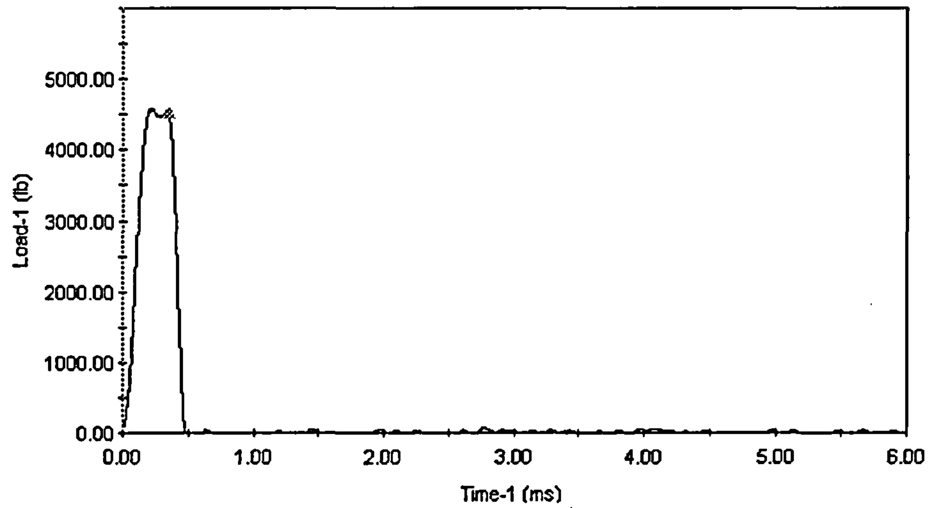
WL60, -50°F



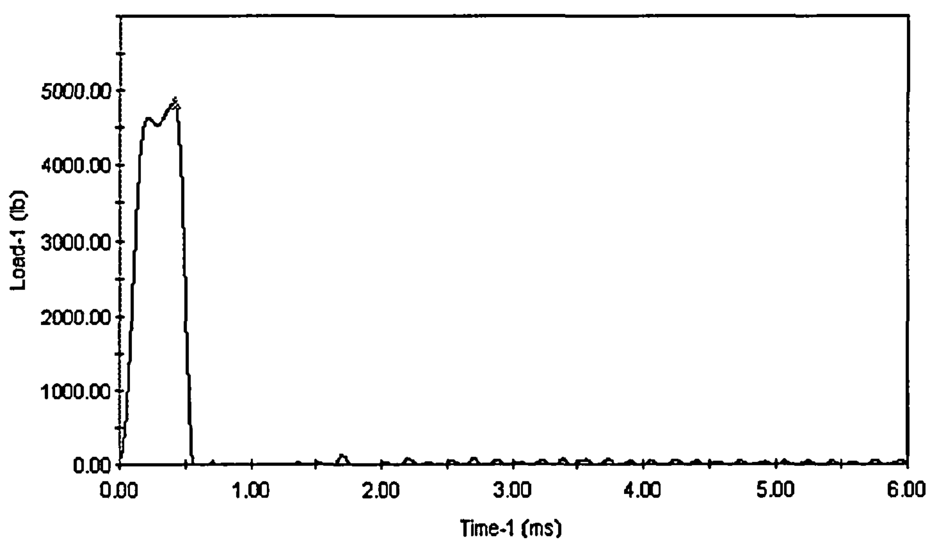
WL54, -25°F



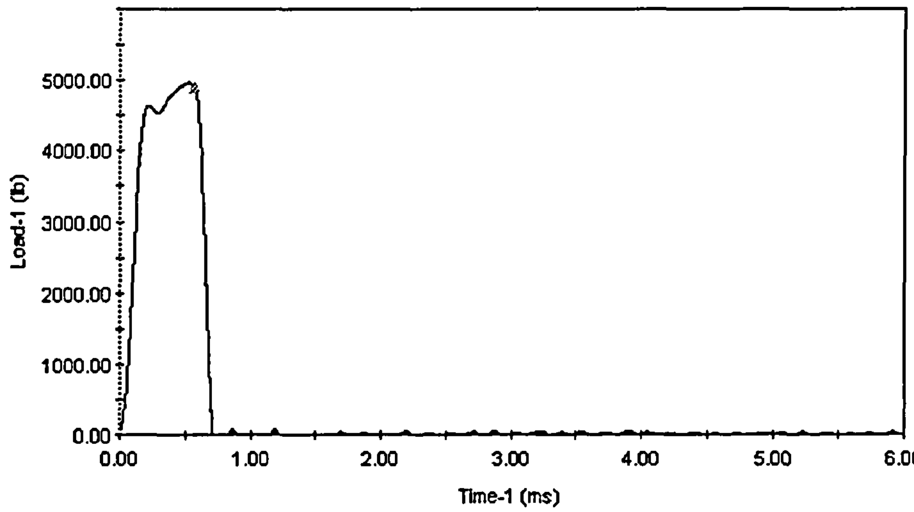
WL50, 0°F



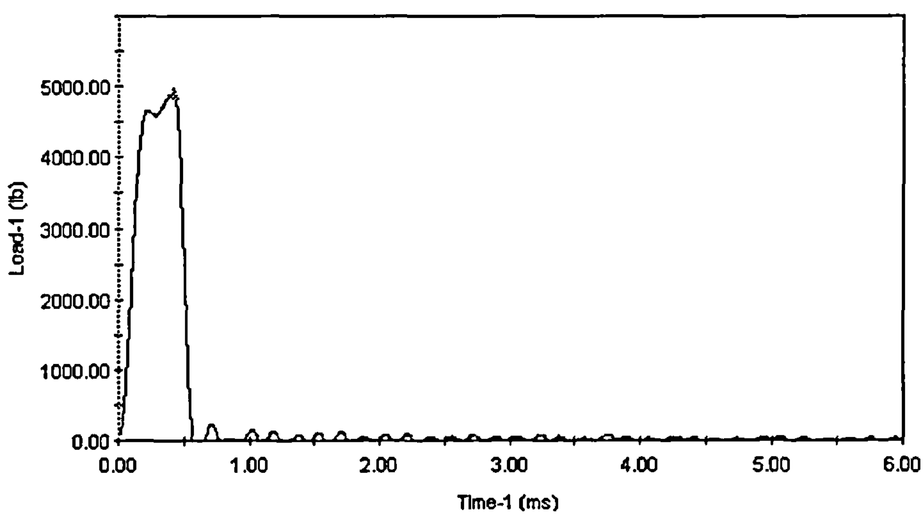
WL47, 25°F



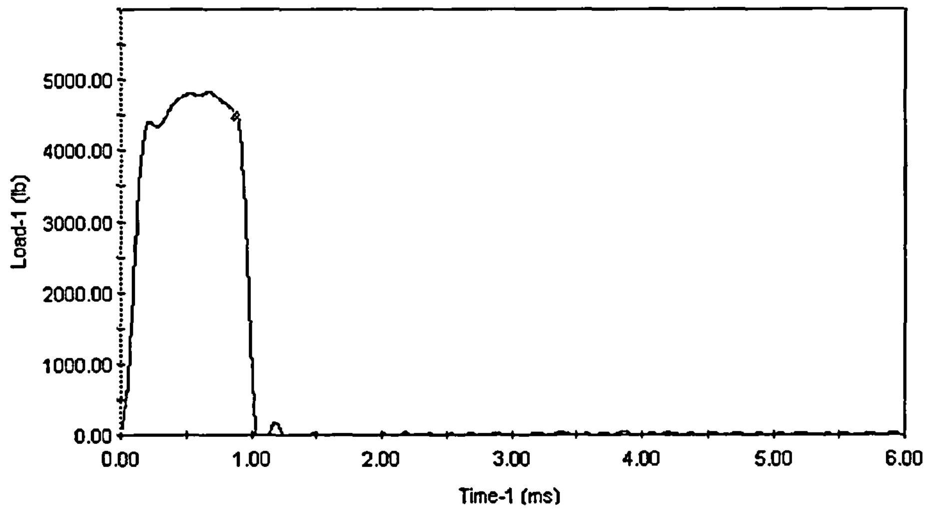
WL52, 40°F



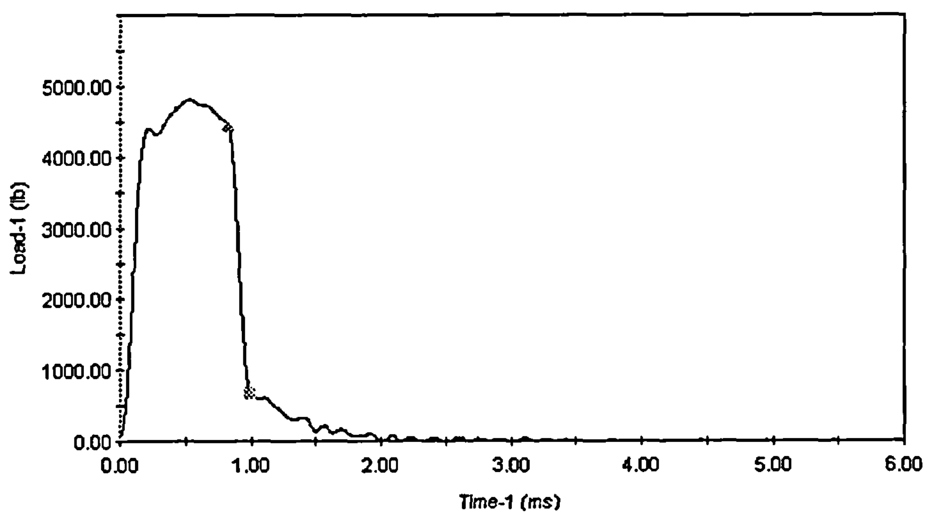
WL57, 50°F



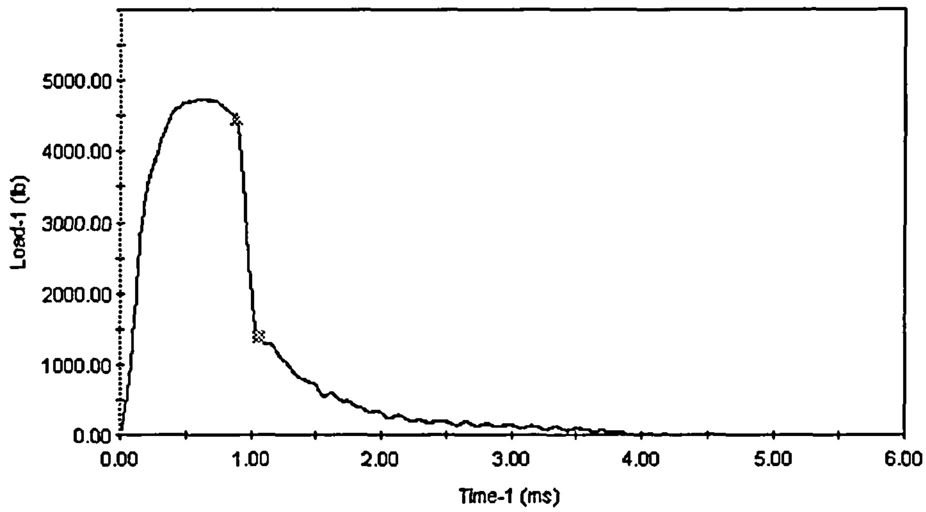
WL51, 75°F



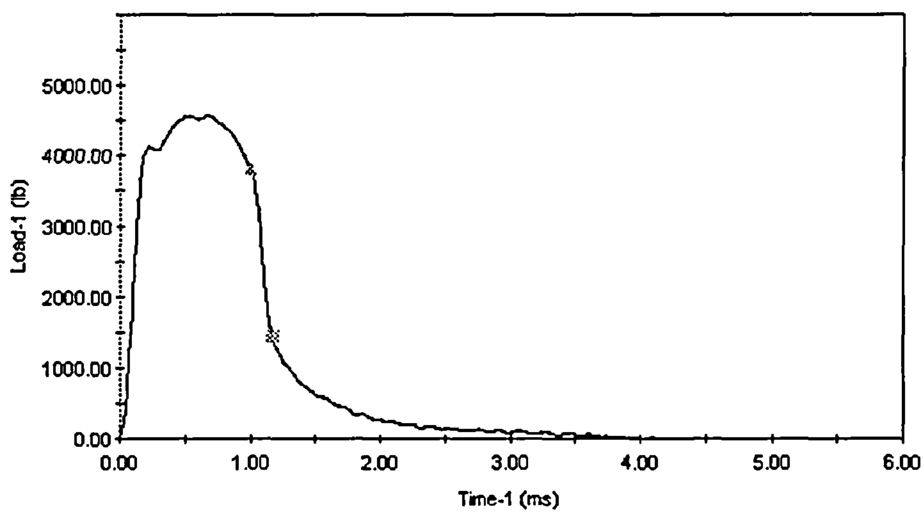
WL58, 100°F



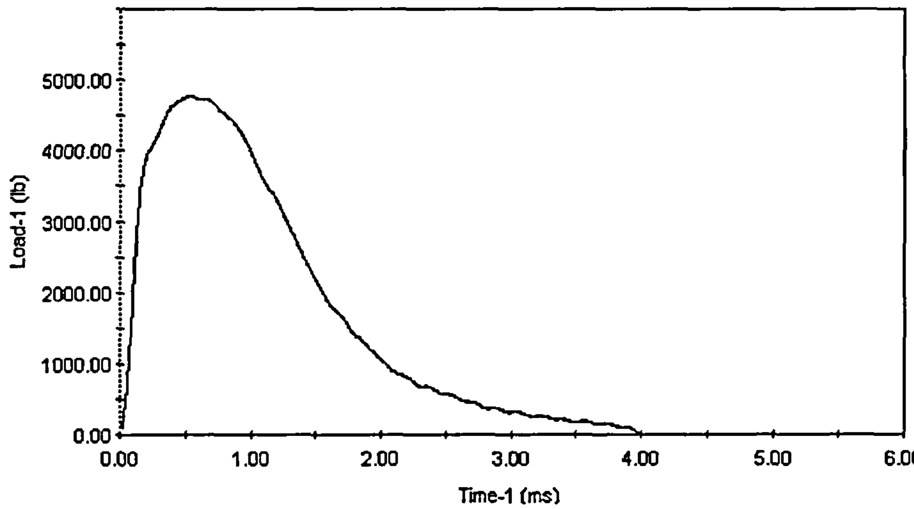
WL53, 125°F



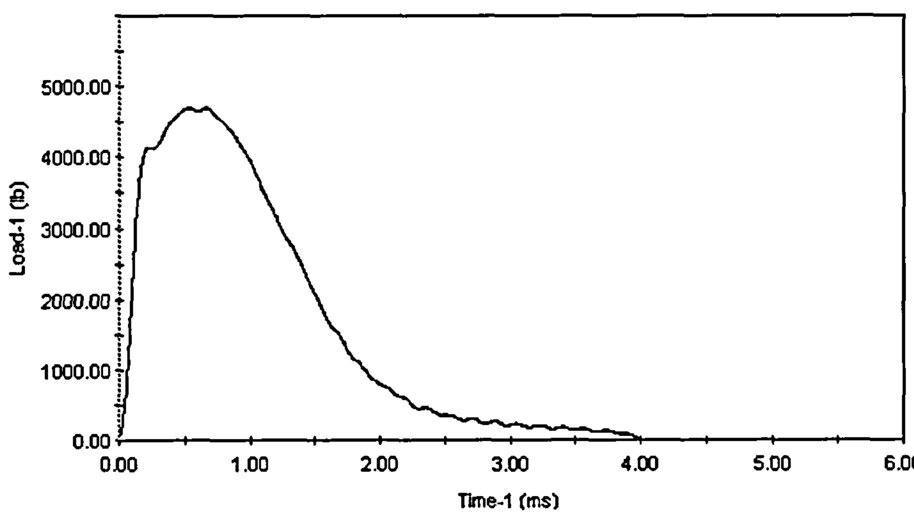
WL56, 160°F



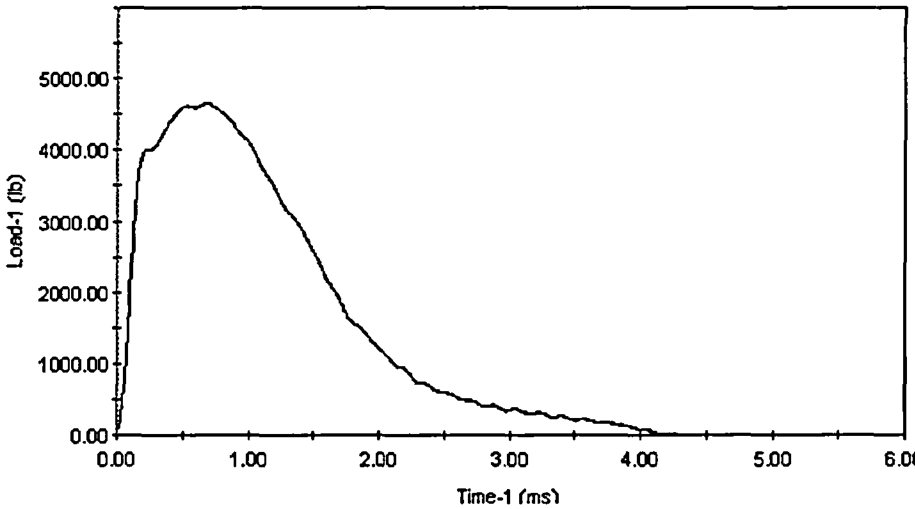
WL59, 180°F



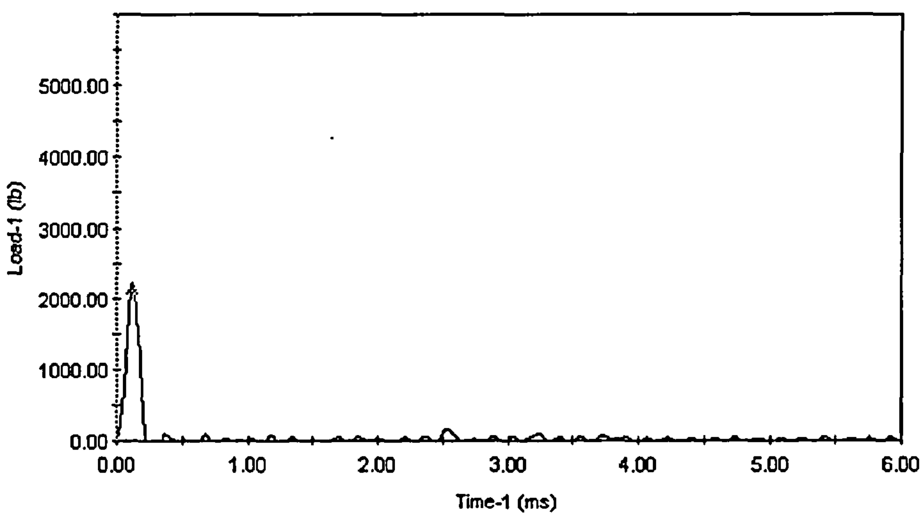
WL49, 225°F



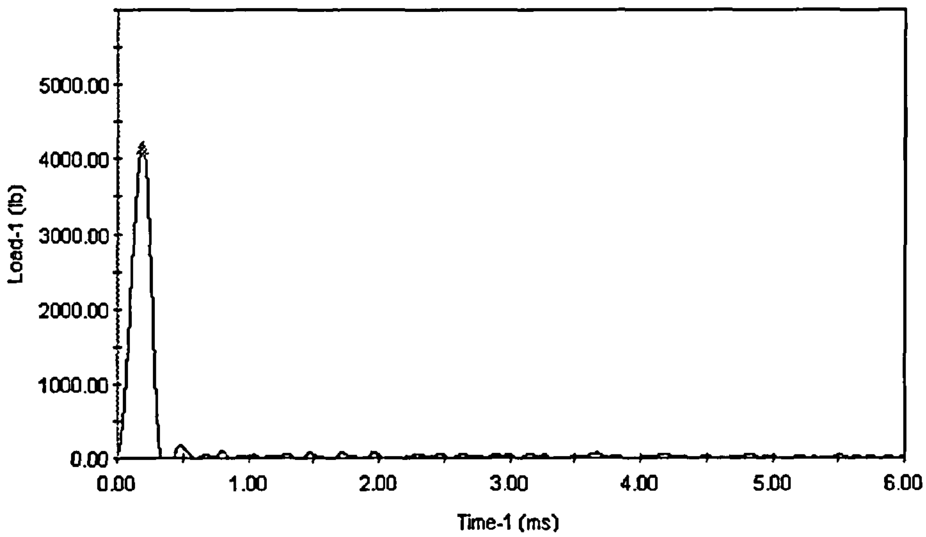
WL46, 250°F



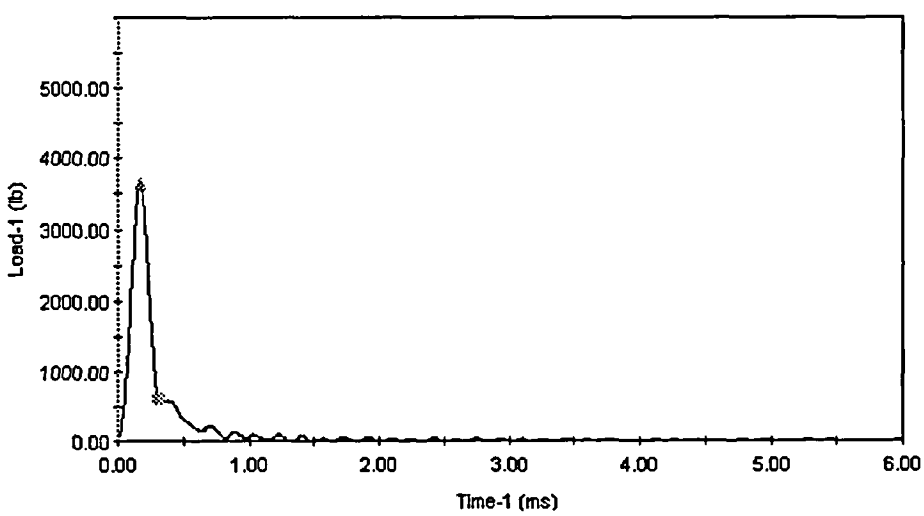
WL48, 250°F



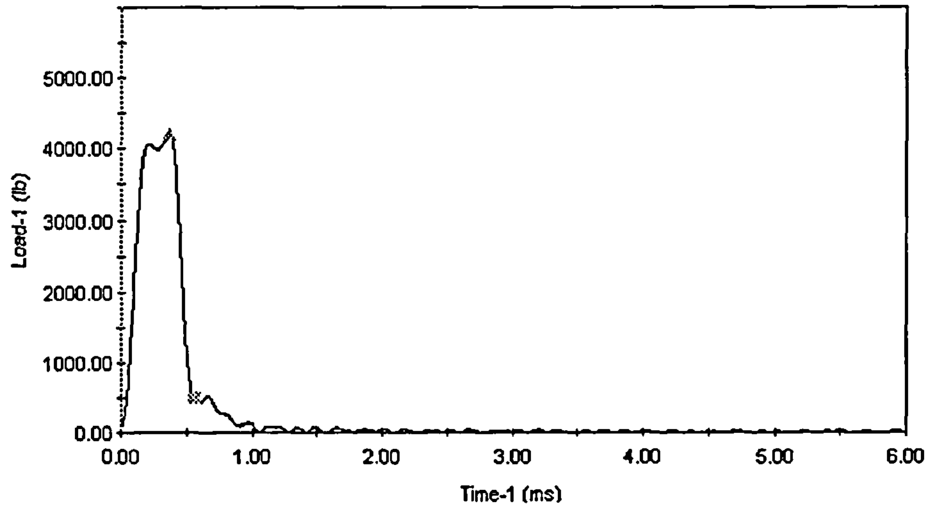
WT60, 0°F



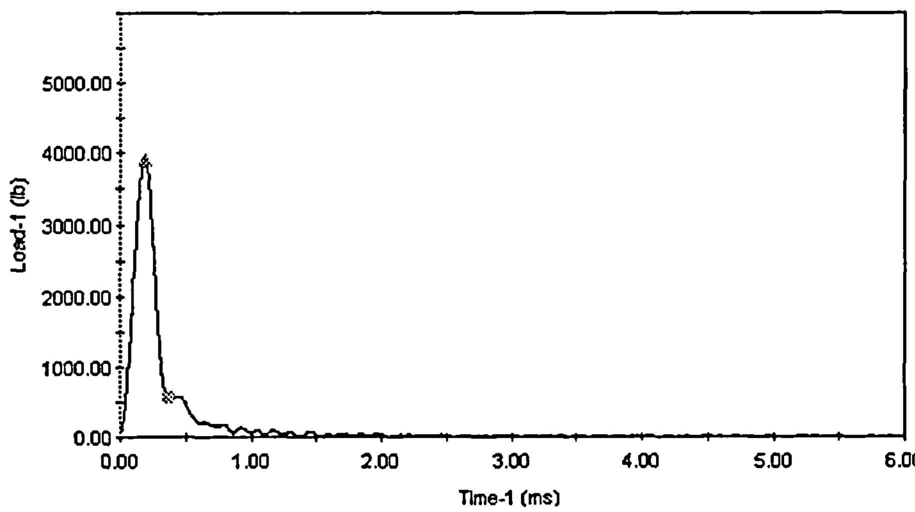
WT47, 50°F



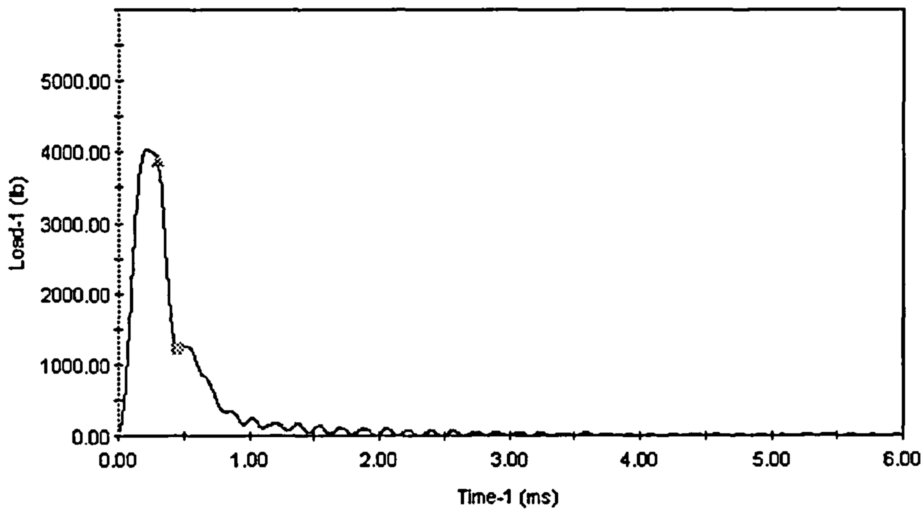
WT57, 100°F



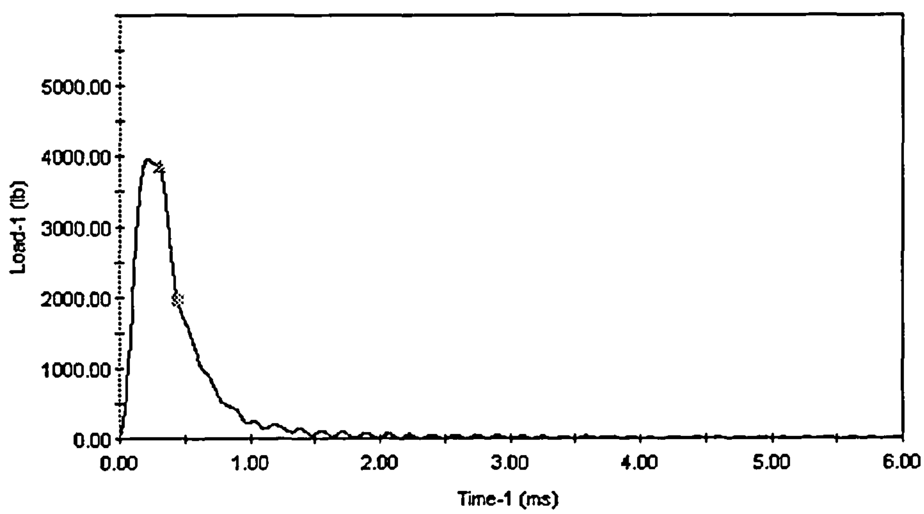
WT54, 125°F



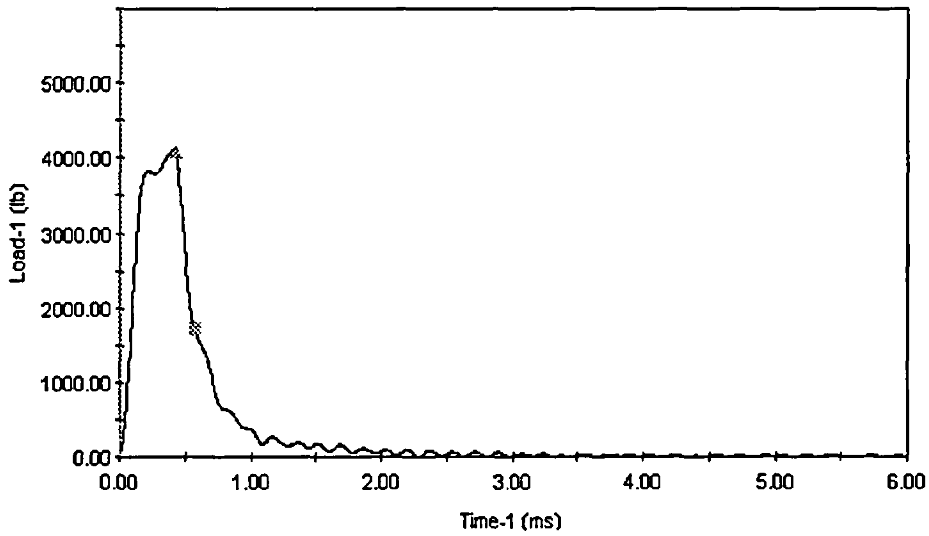
WT49, 125°F



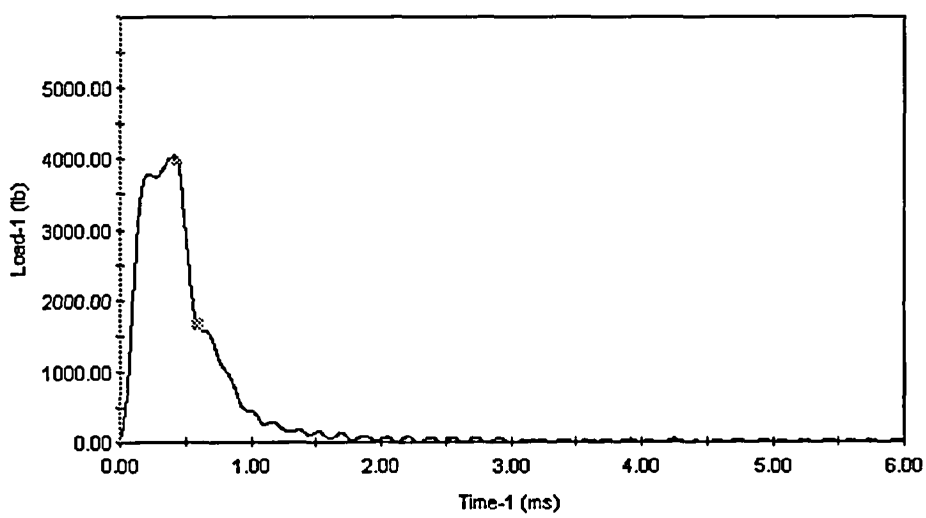
WT56, 150°F



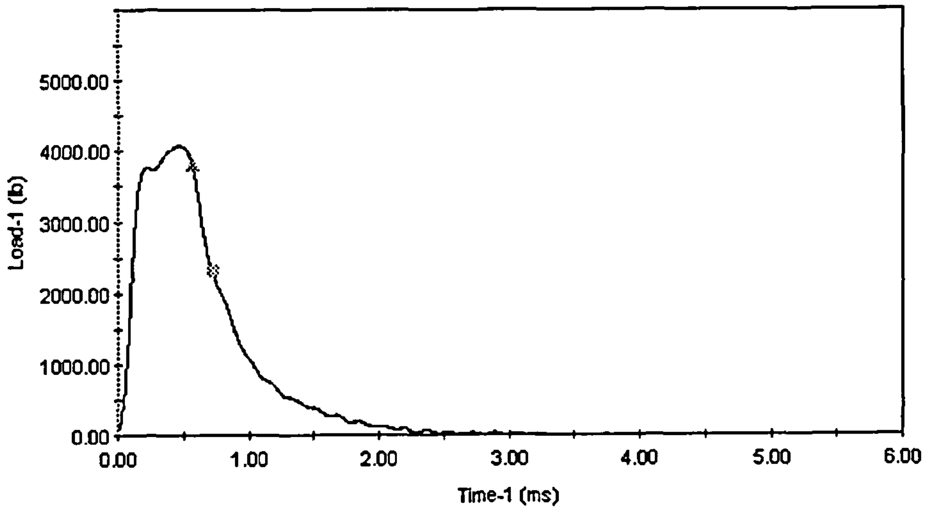
WT58, 175°F



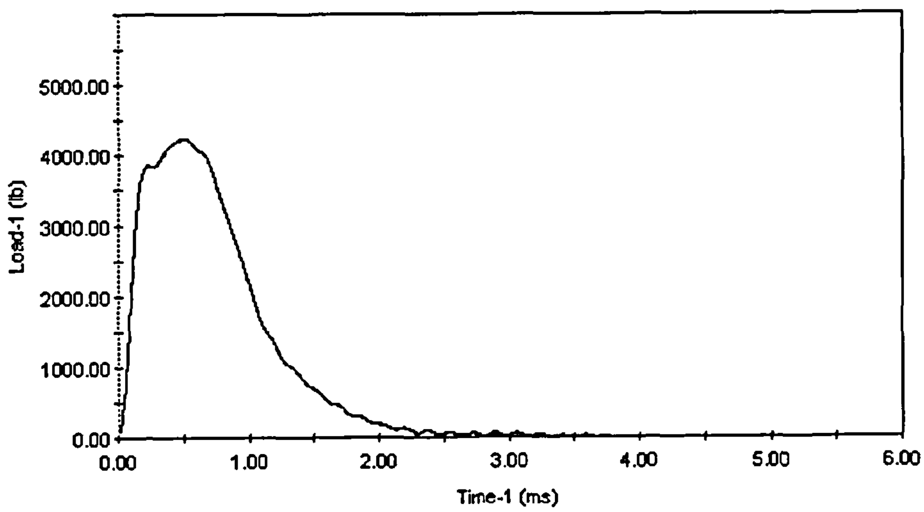
WT59, 200°F



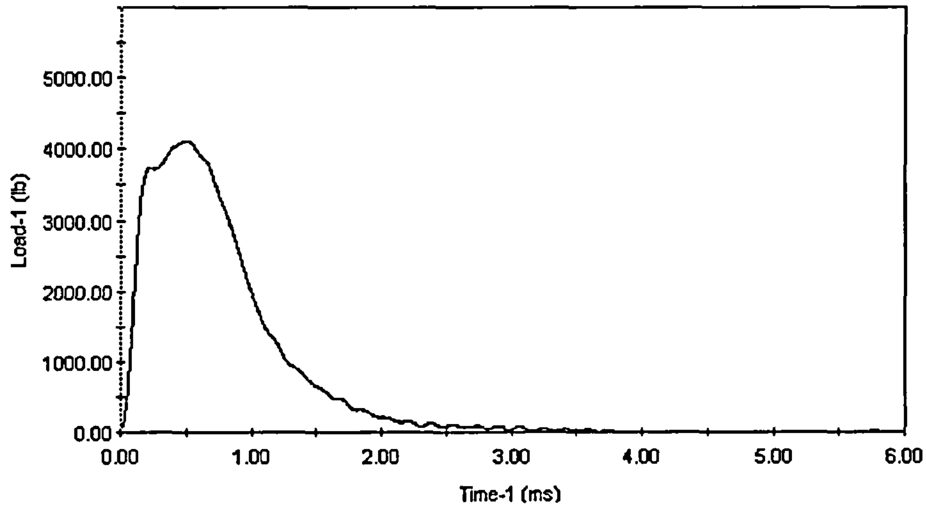
WT46, 210°F



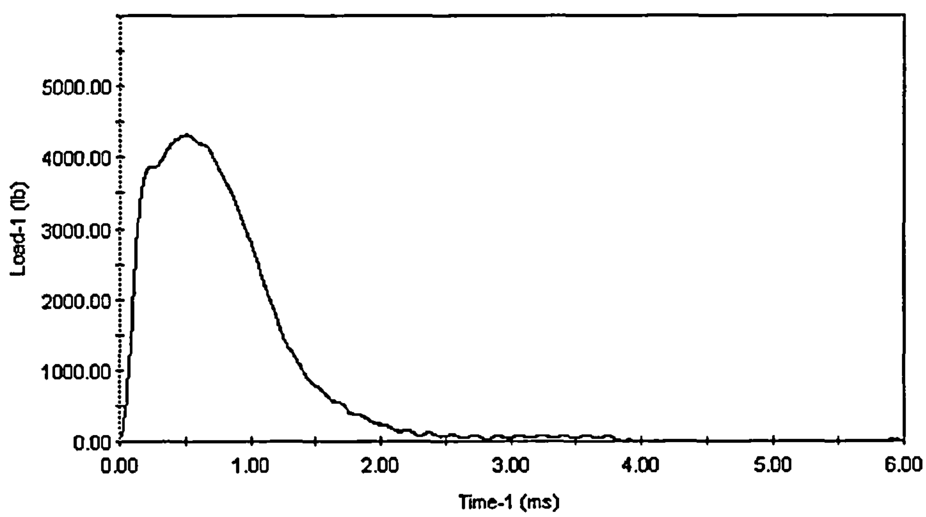
WT50, 225°F



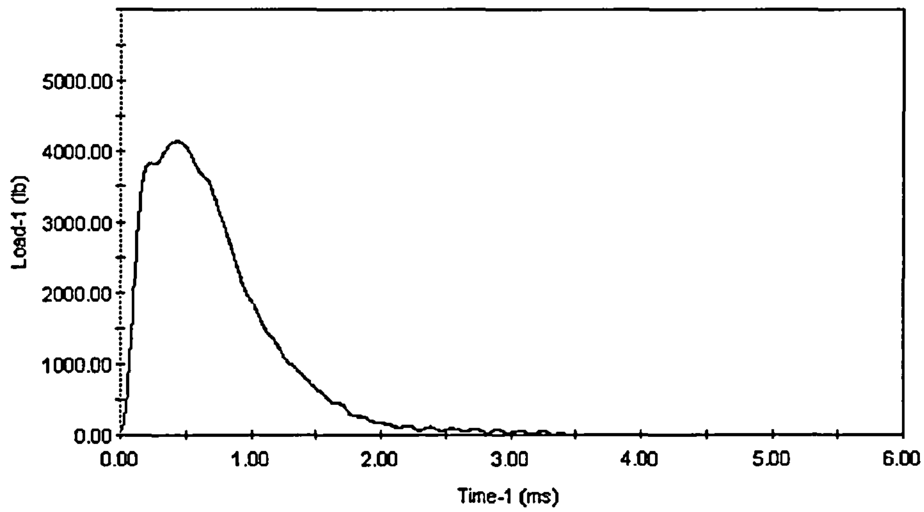
WT51, 250°F



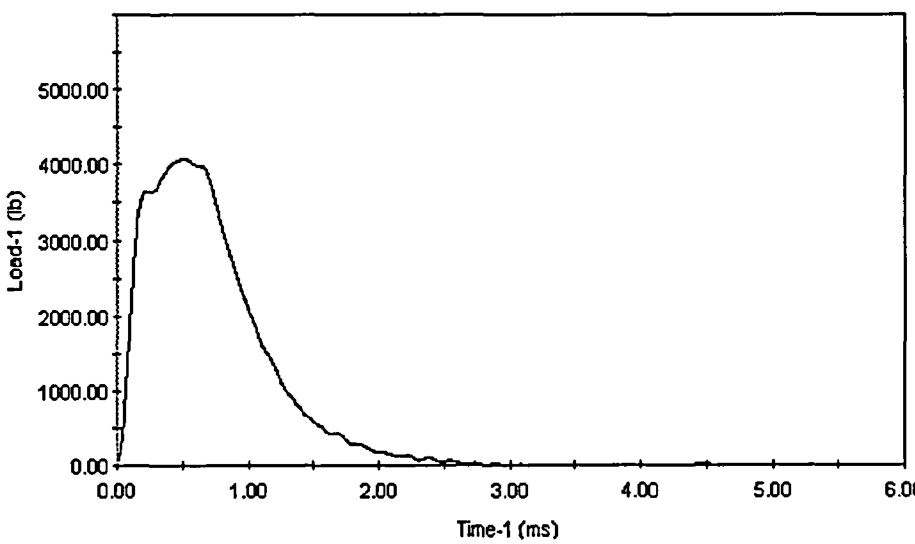
WT53, 250°F



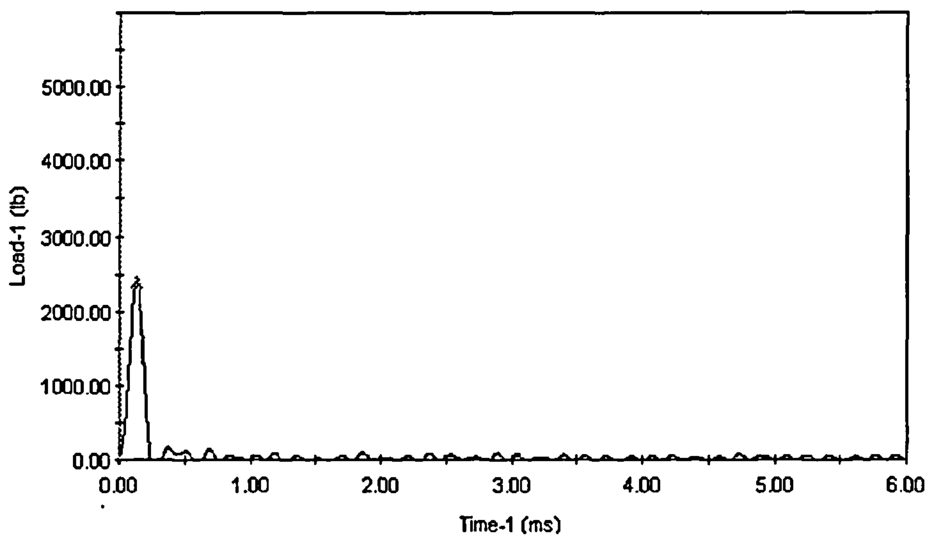
WT48, 275°F



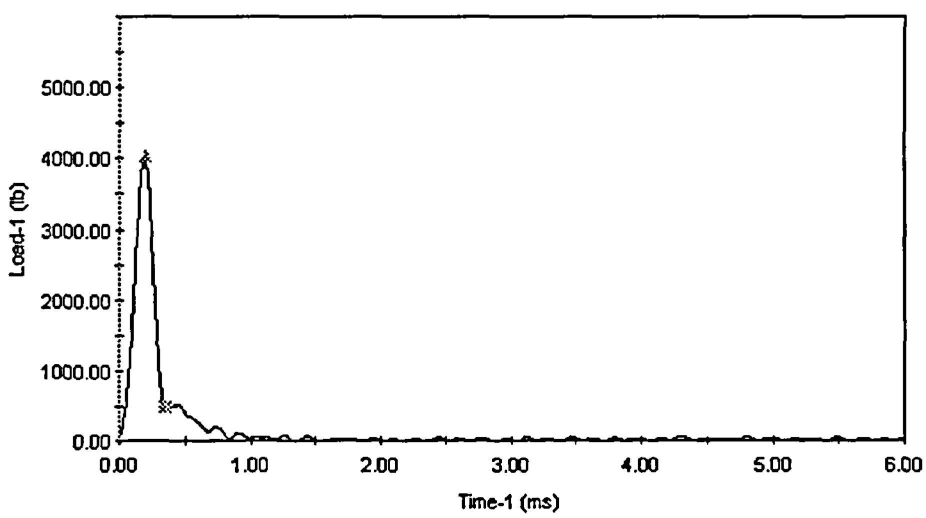
WT52, 275°F



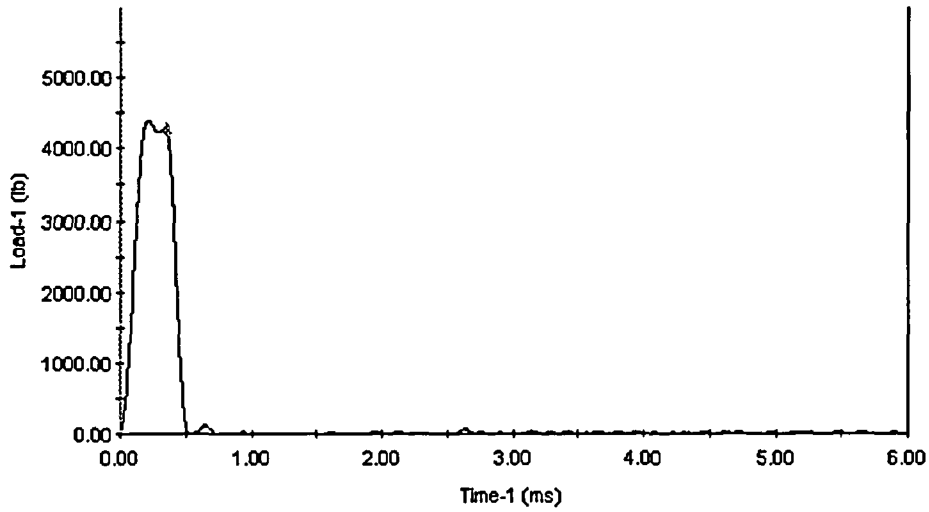
WT55, 300°F



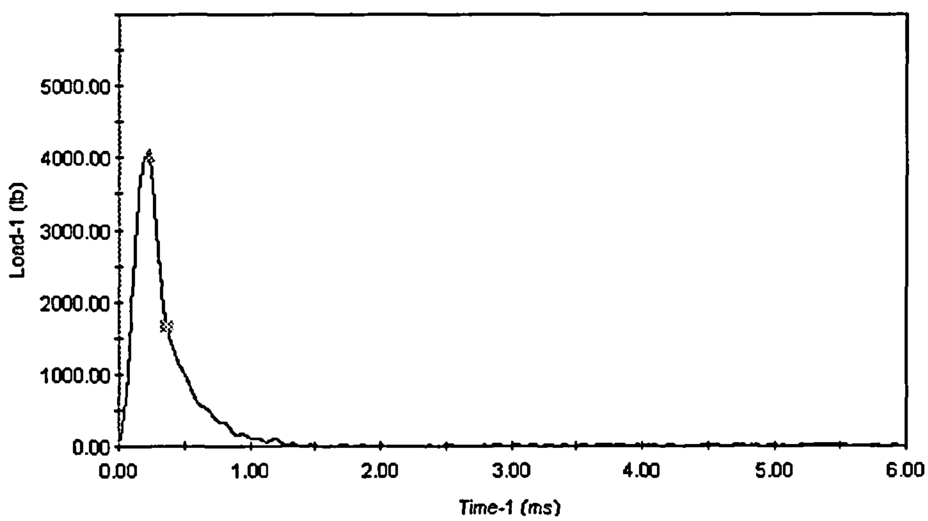
WW55, -100°F



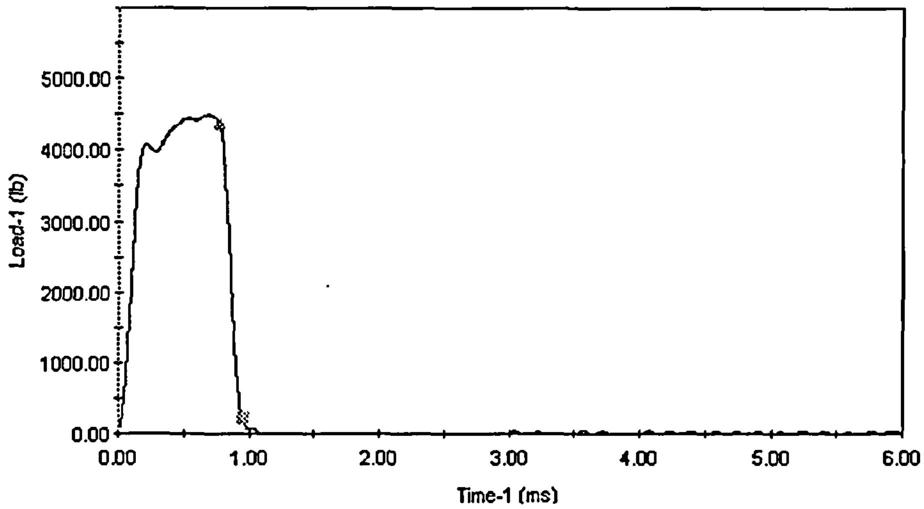
WW47, -75°F



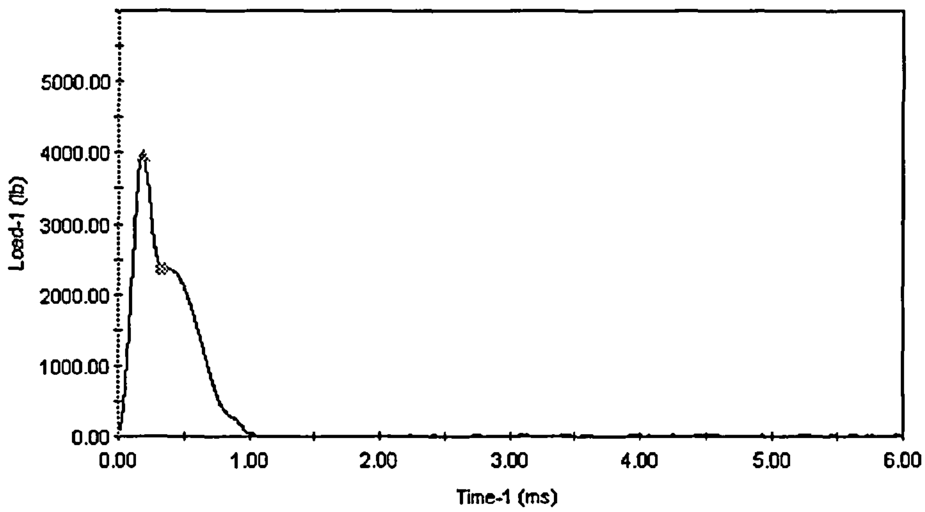
WW46, -50°F



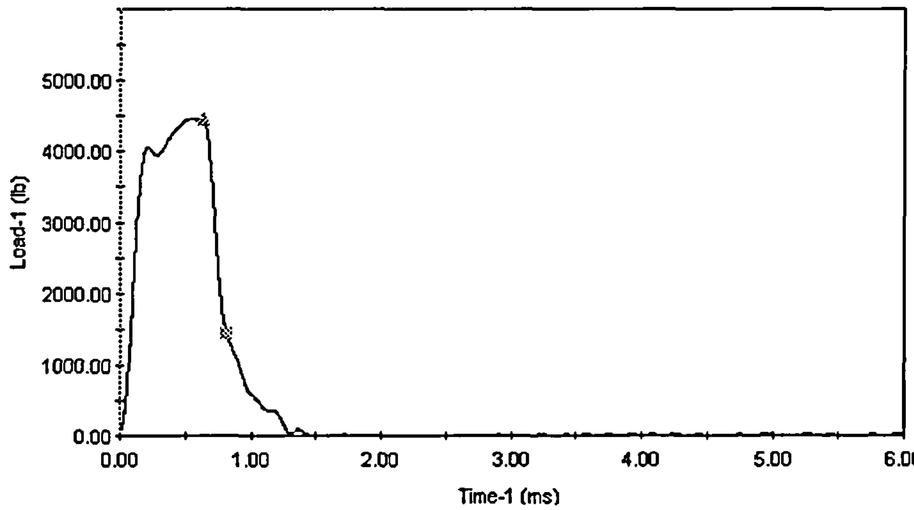
WW48, -25°F



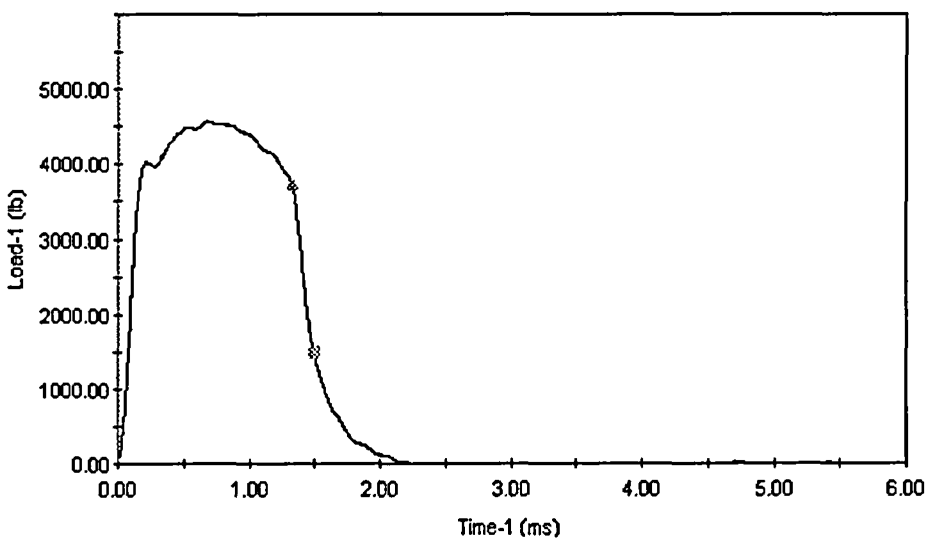
WW52, 10°F



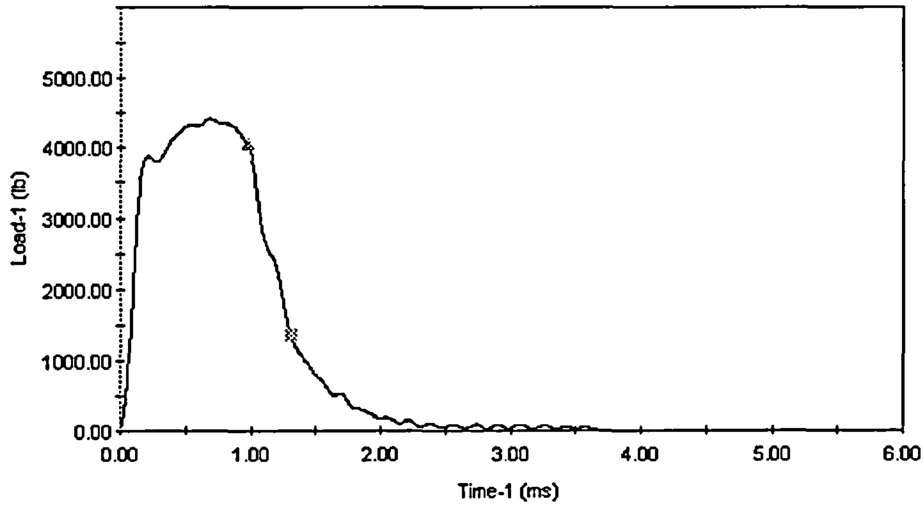
WW59, 25°F



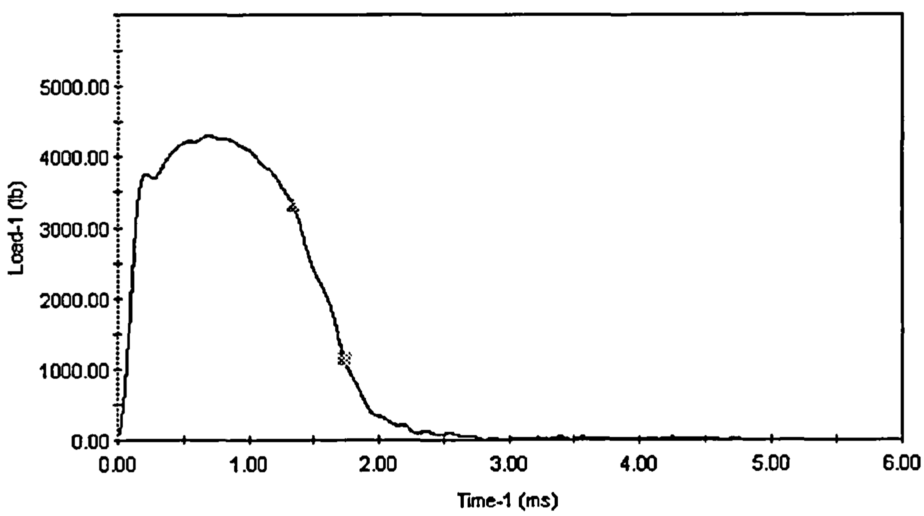
WW57, 50°F



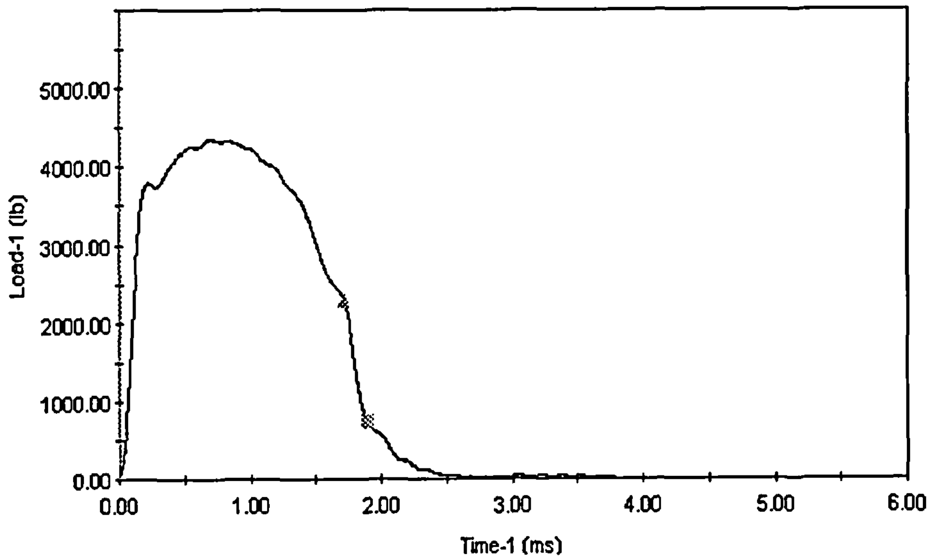
WW49, 75°F



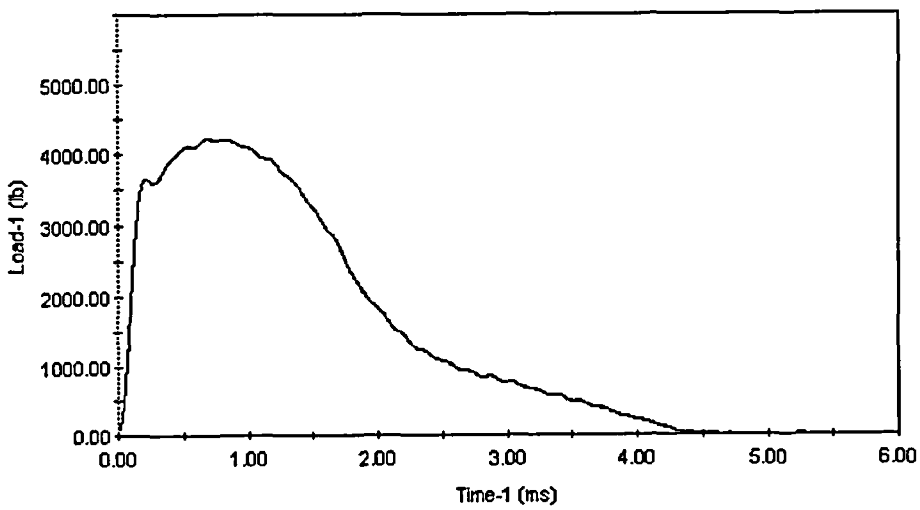
WW53, 100°F



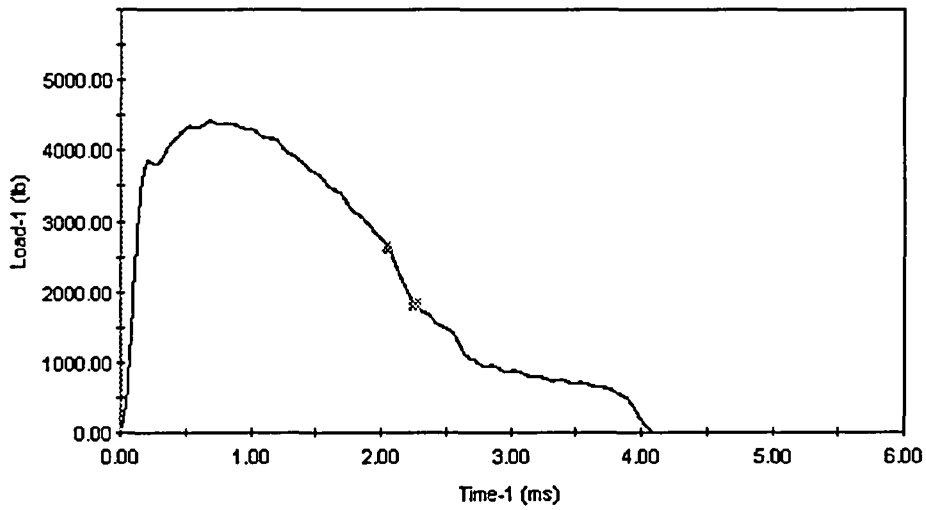
WW50, 125°F



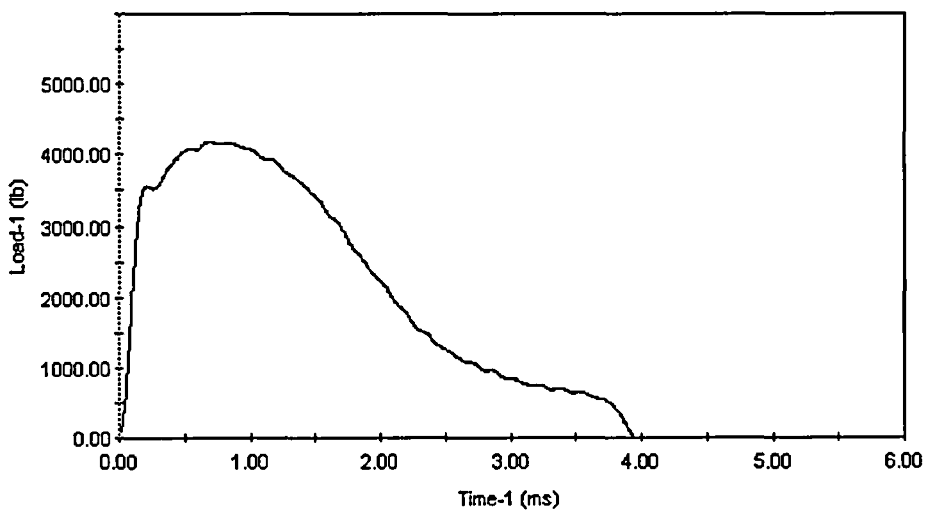
WW60, 175°F



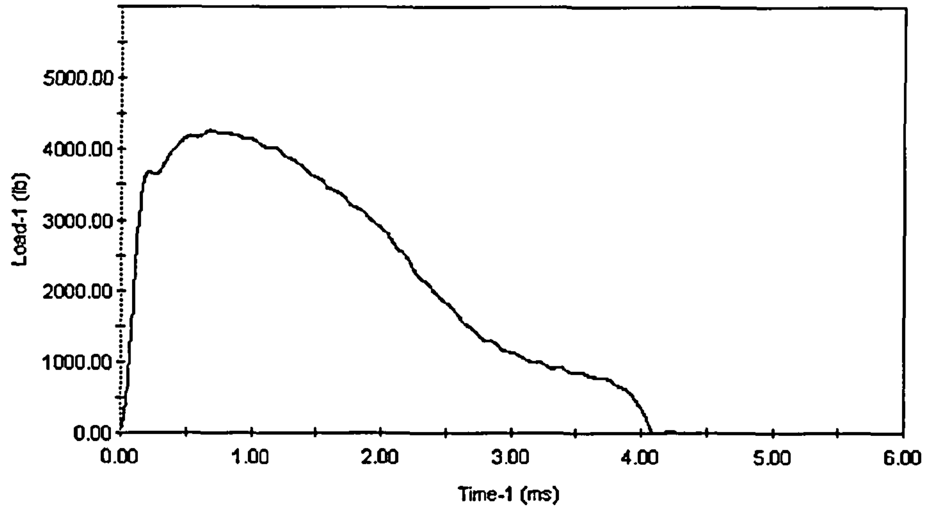
WW56, 200°F



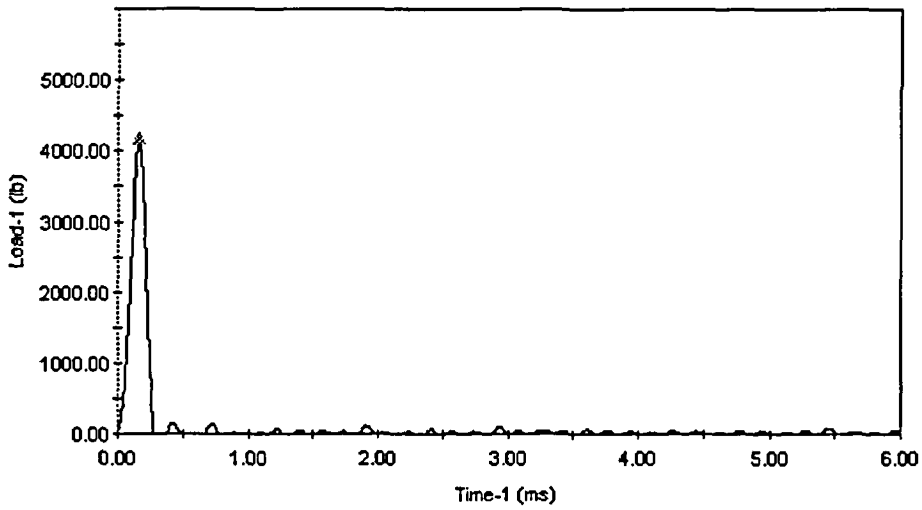
WW58, 225°F



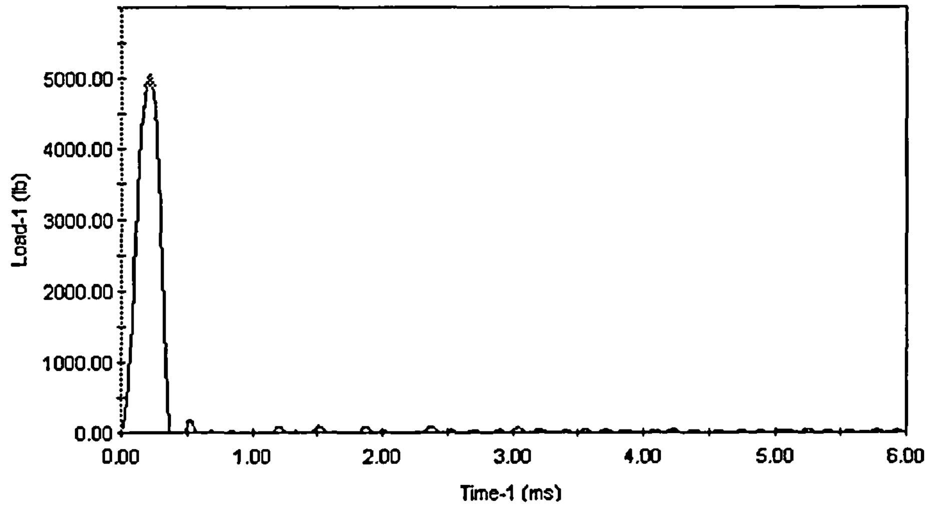
WW54, 225°F



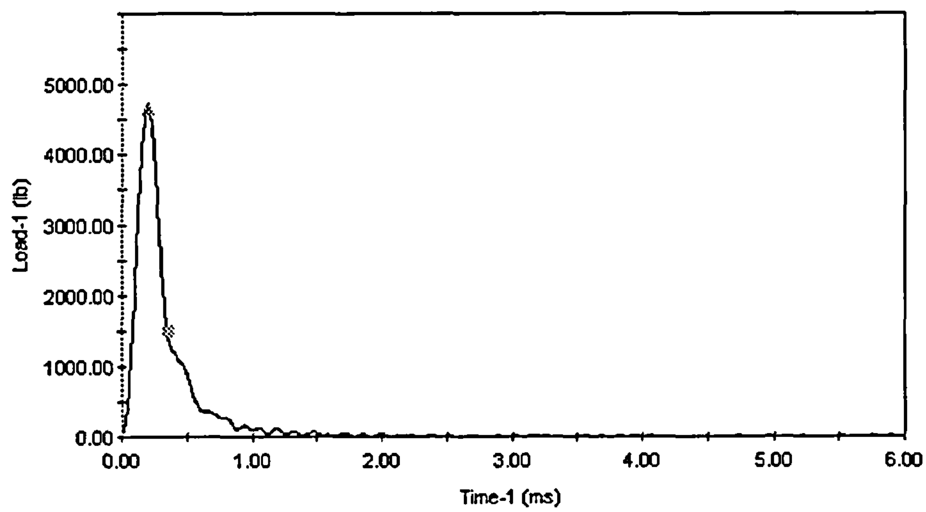
WW51, 275°F



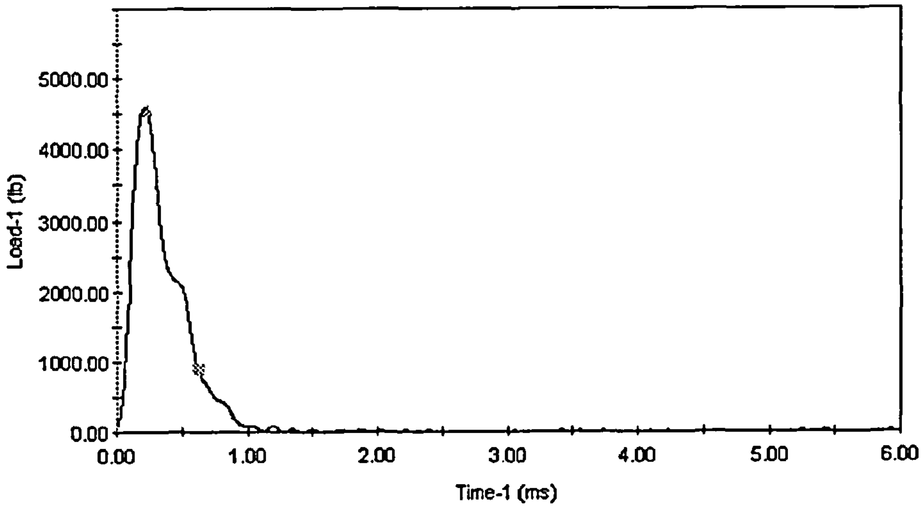
WH54, -75°F



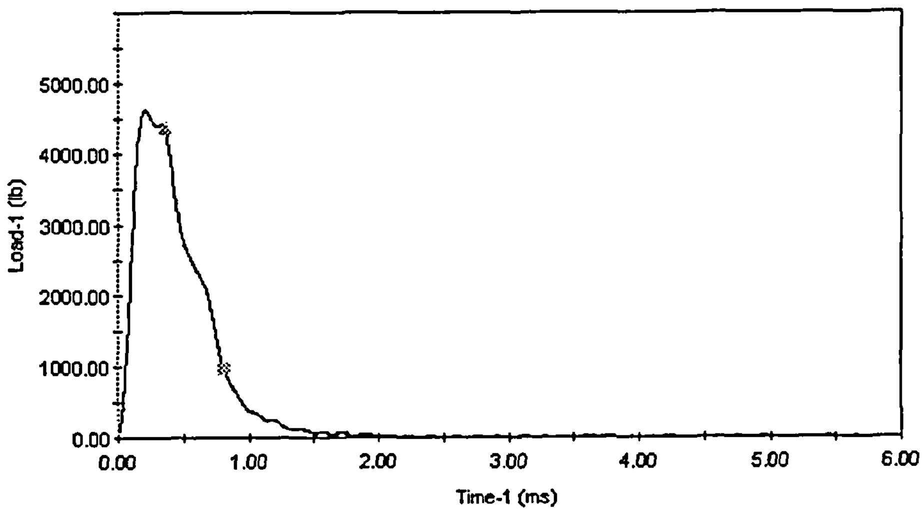
WH51, -50°F



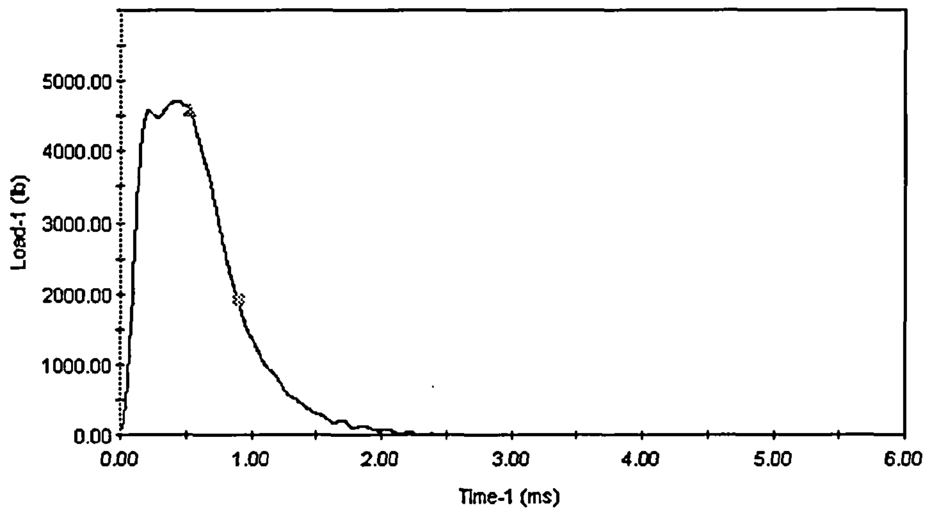
WH50, 0°F



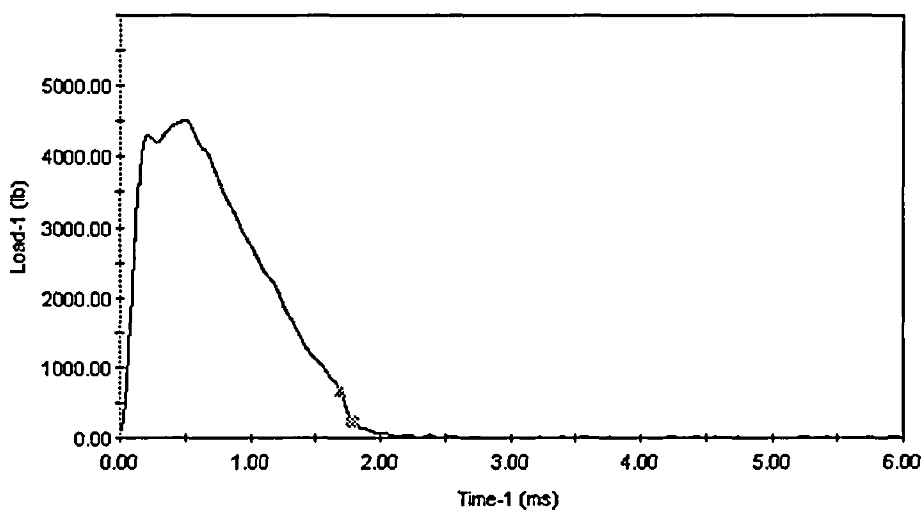
WH56, 25°F



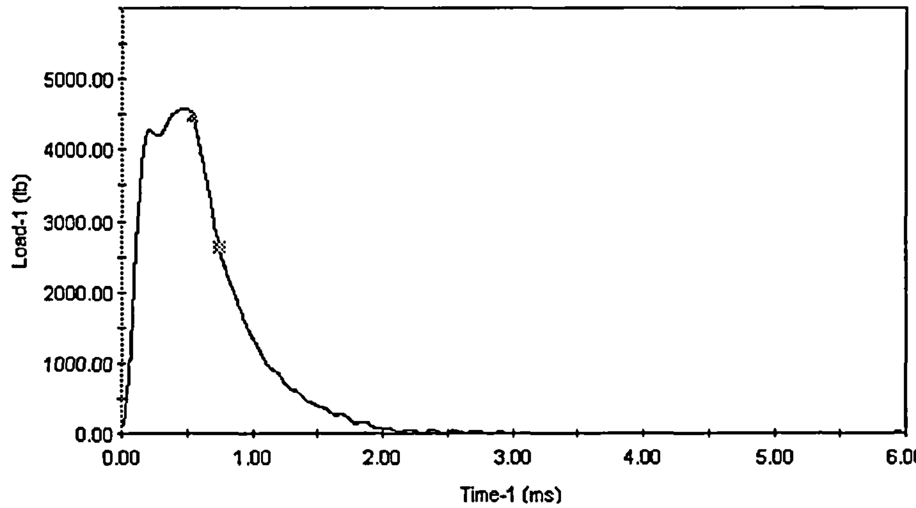
WH46, 50°F



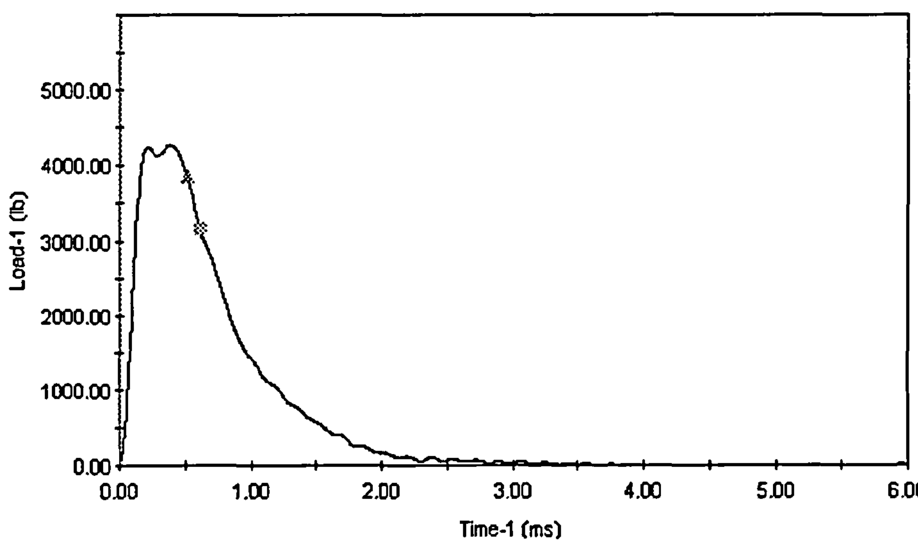
WH47, 75°F



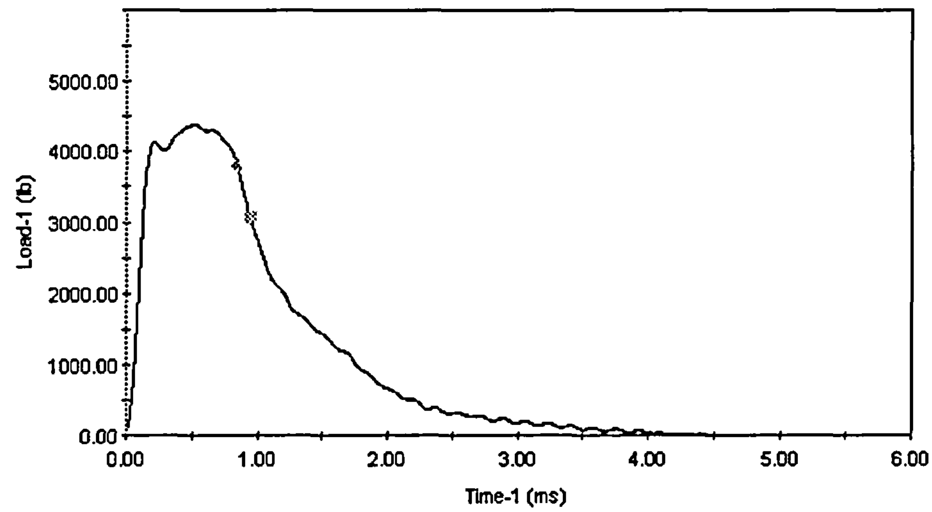
WH55, 100°F



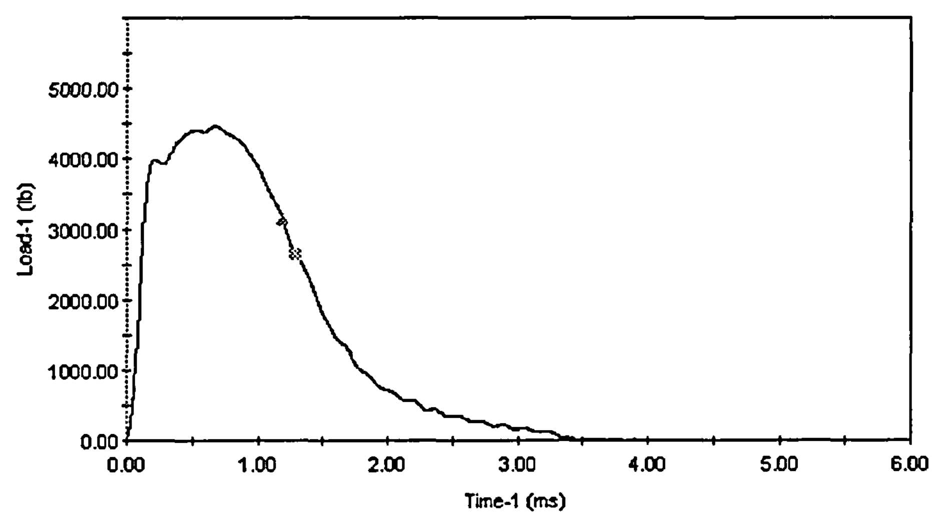
WH49, 125°F



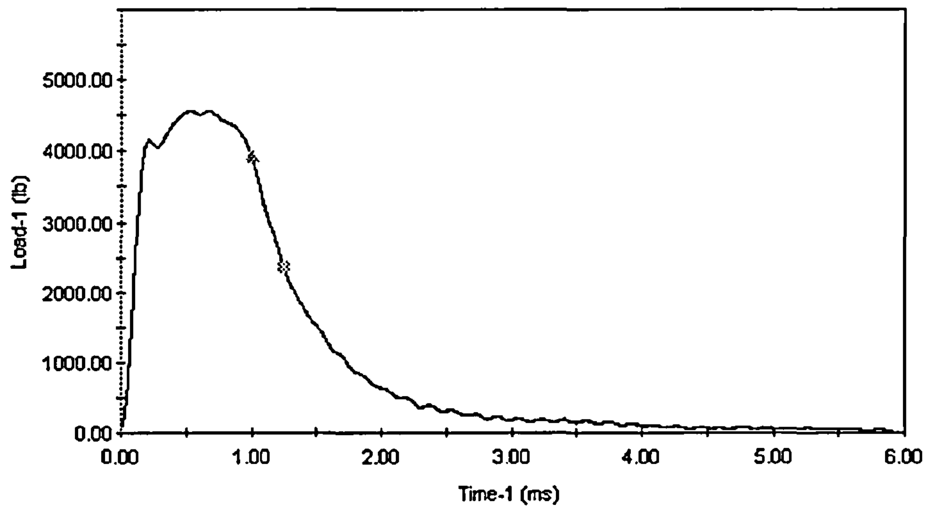
WH52, 150°F



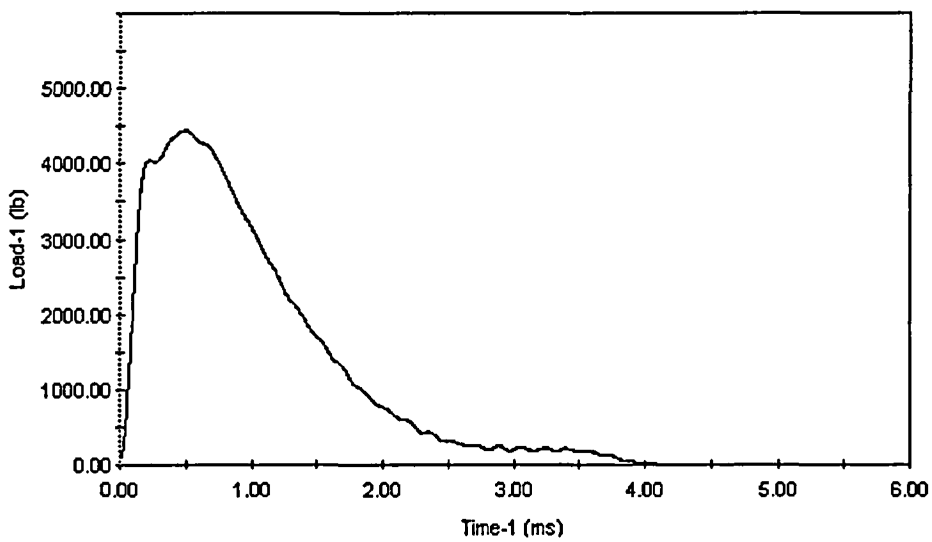
WH48, 200°F



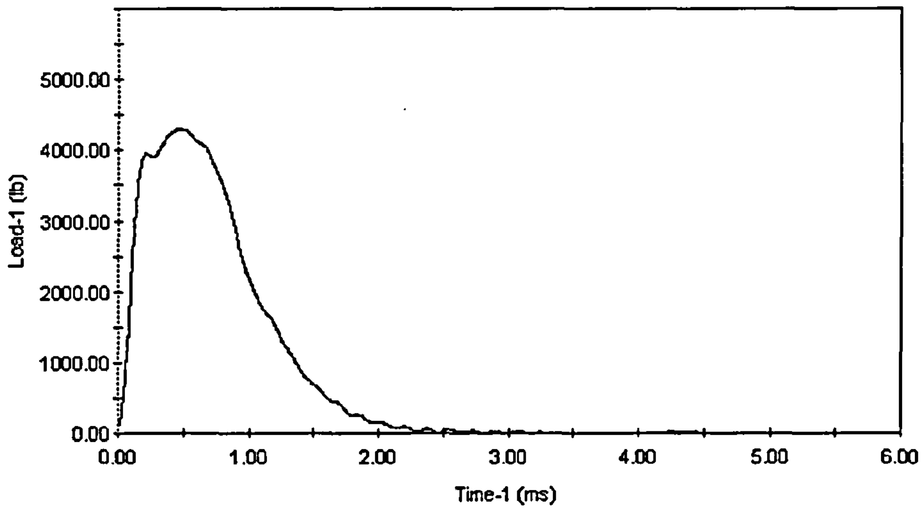
WH58, 200°F



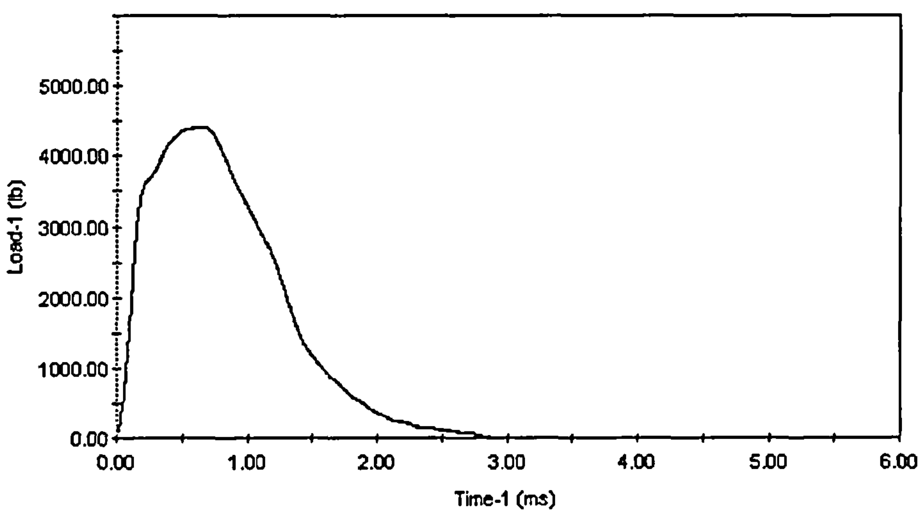
WH53, 225°F



WH59, 250°F



WH60, 275°F



WH57, 300°F

APPENDIX C

CHARPY V-NOTCH PLOTS FOR EACH CAPSULE USING SYMMETRIC HYPERBOLIC TANGENT CURVE-FITTING METHOD

Contained in Table C-1 are the upper shelf energy values used as input for the generation of the Charpy V-notch plots using CVGRAPH, Version 5.0.2. The definition for Upper Shelf Energy (USE) is given in ASTM E185-82, Section 4.18, and reads as follows:

> "*upper shelf energy level* – the average energy value for all Charpy specimens (normally three) whose test temperature is above the upper end of the transition region. For specimens tested in sets of three at each test temperature, the set having the highest average may be regarded as defining the upper shelf energy."

If there are specimens tested in set of three at each temperature Westinghouse reports the set having the highest average energy as the USE (usually unirradiated material). If the specimens were not tested in sets of three at each temperature Westinghouse reports the average of all 100% shear Charpy data as the USE. Hence, the USE values reported in Table C-1 and used to generate the Charpy V-notch curves were determined utilizing this methodology.

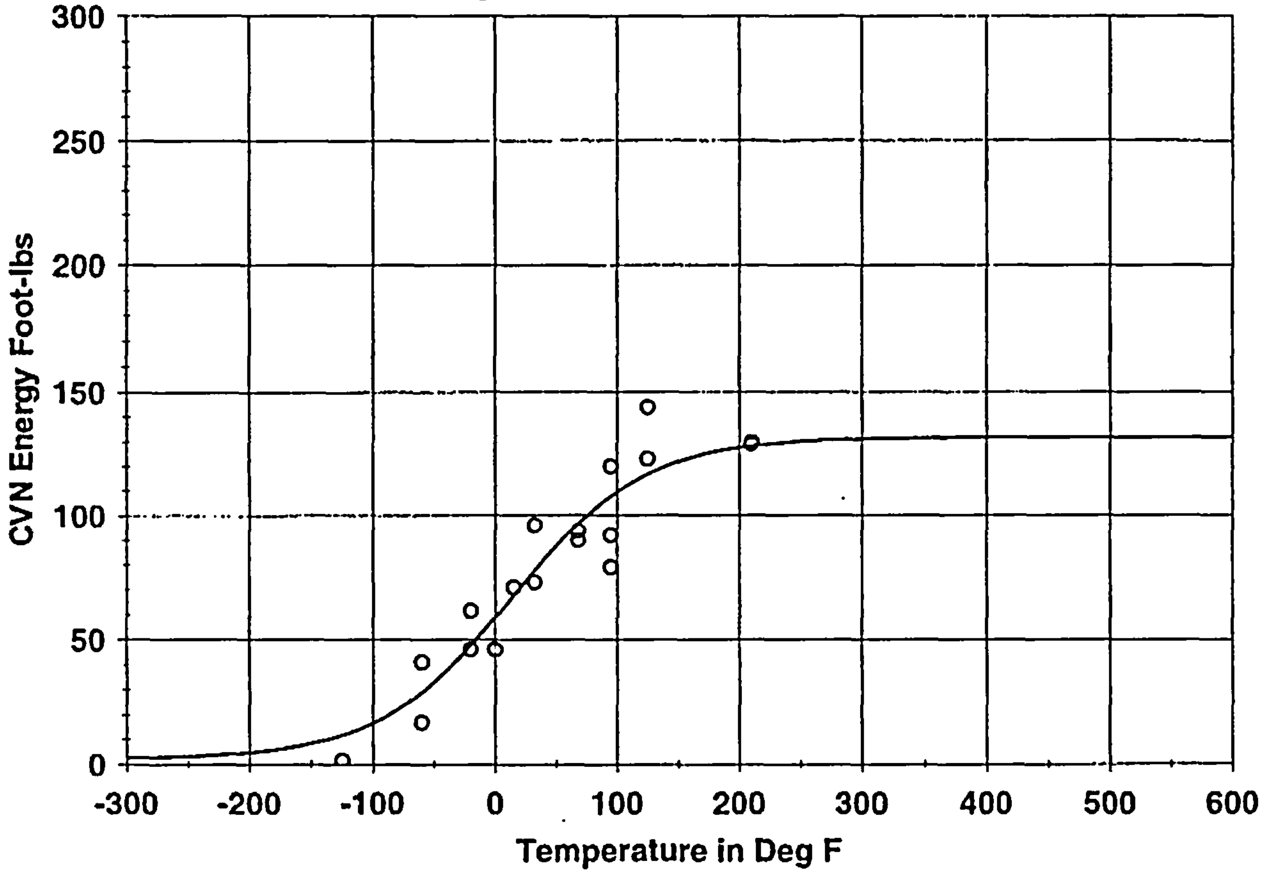
The lower shelf energy values were fixed at 2.2 ft-lb for all cases.

Table C-1 Upper Shelf Energy Values Fixed in CVGRAPH [ft-lb]

Material	Unirradiated	Capsule U	Capsule W	Capsule X
Intermediate Shell Forging 05 (Tangential)	132	107	98	106
Intermediate Shell Forging 05 (Axial)	62	72	60	66
Weld Metal (heat # 895075)	131	143	112	134
HAZ Material	89	79	77	80

UNIRRADIATED INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/06/2004 11:07 AM
Page 1
Coefficients of Curve 1
A = 67.1 B = 64.9 C = 109.84 T0 = 14.2 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=132.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-57.1 Deg F Temp@50 ft-lbs=-15.4 Deg F
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: UNIRR Fluence: 0.0 n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-125.00	1.50	11.74	-10.24
-60.00	41.00	28.90	12.10
-60.00	17.00	28.90	-11.90
-20.00	46.00	47.52	-1.52
-20.00	61.50	47.52	13.98
.00	46.00	58.75	-12.75
15.00	71.00	67.57	3.43
32.00	73.00	77.52	-4.52
32.00	96.00	77.52	18.48

UNIRRADIATED INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: WATTS BAR 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: UNIRR Fluence: 0.0 n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
68.00	93.50	96.57	-3.07
68.00	90.00	96.57	-6.57
95.00	120.00	107.76	12.24
95.00	79.00	107.76	-28.76
95.00	92.00	107.76	-15.76
125.00	123.00	116.76	6.24
125.00	144.00	116.76	27.24
210.00	130.00	128.43	1.57
210.00	129.00	128.43	.57

Correlation Coefficient = .941

UNIRRADIATED INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/06/2004 02:08 PM

Page 1

Coefficients of Curve 1

A = 40.26 B = 40.26 C = 87.82 T0 = 2.05 D = 0.00E+00

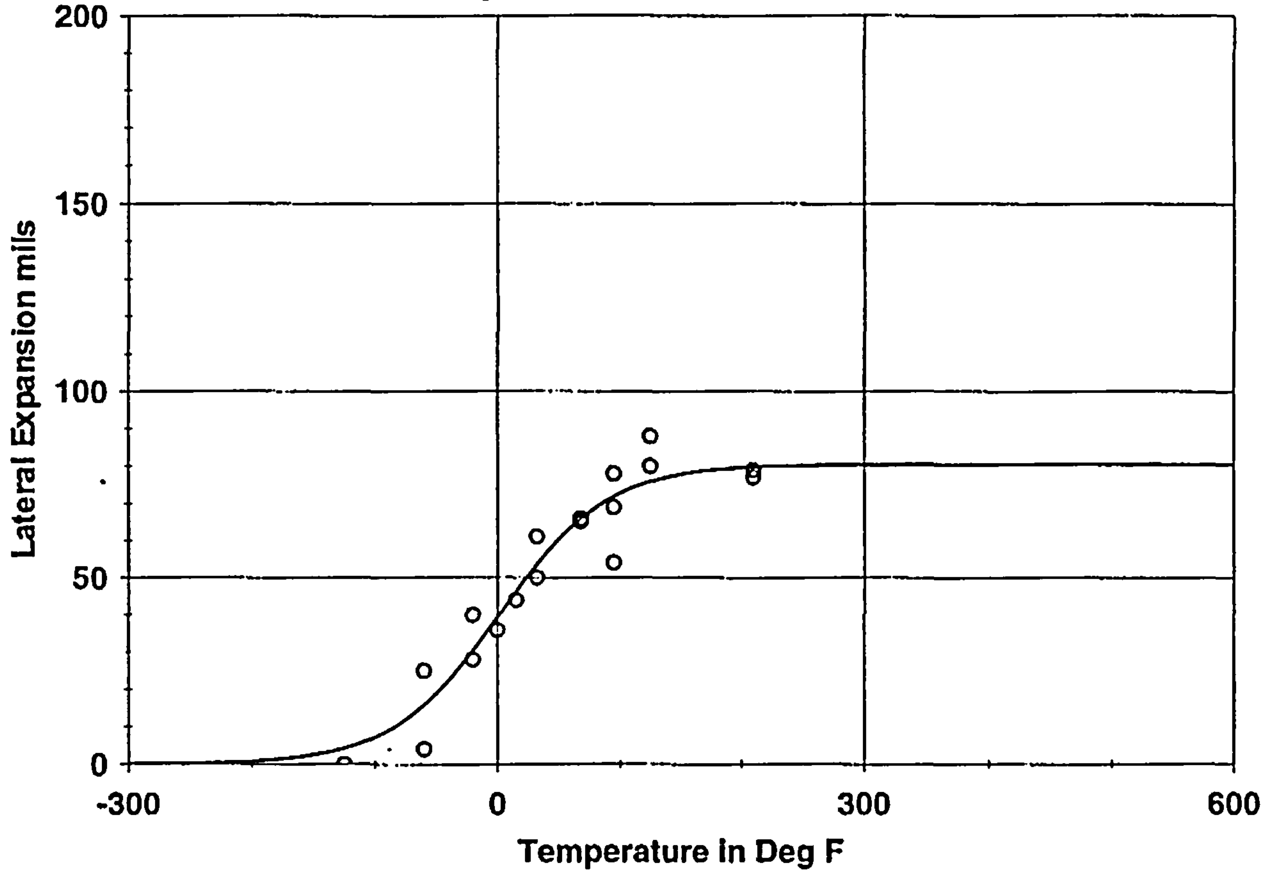
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=80.5 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=-9.4 Deg F

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536

Orientation: LT Capsule: UNIRR Fluence: 0.0 n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-125.00	.00	4.23	-4.23
-60.00	25.00	15.76	9.24
-60.00	4.00	15.76	-11.76
-20.00	28.00	30.35	-2.35
-20.00	40.00	30.35	9.65
.00	36.00	39.31	-3.31
15.00	44.00	46.15	-2.15
32.00	50.00	53.47	-3.47
32.00	61.00	53.47	7.53

UNIRRADIATED INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: UNIRR Fluence: 0.0 n/cm^2

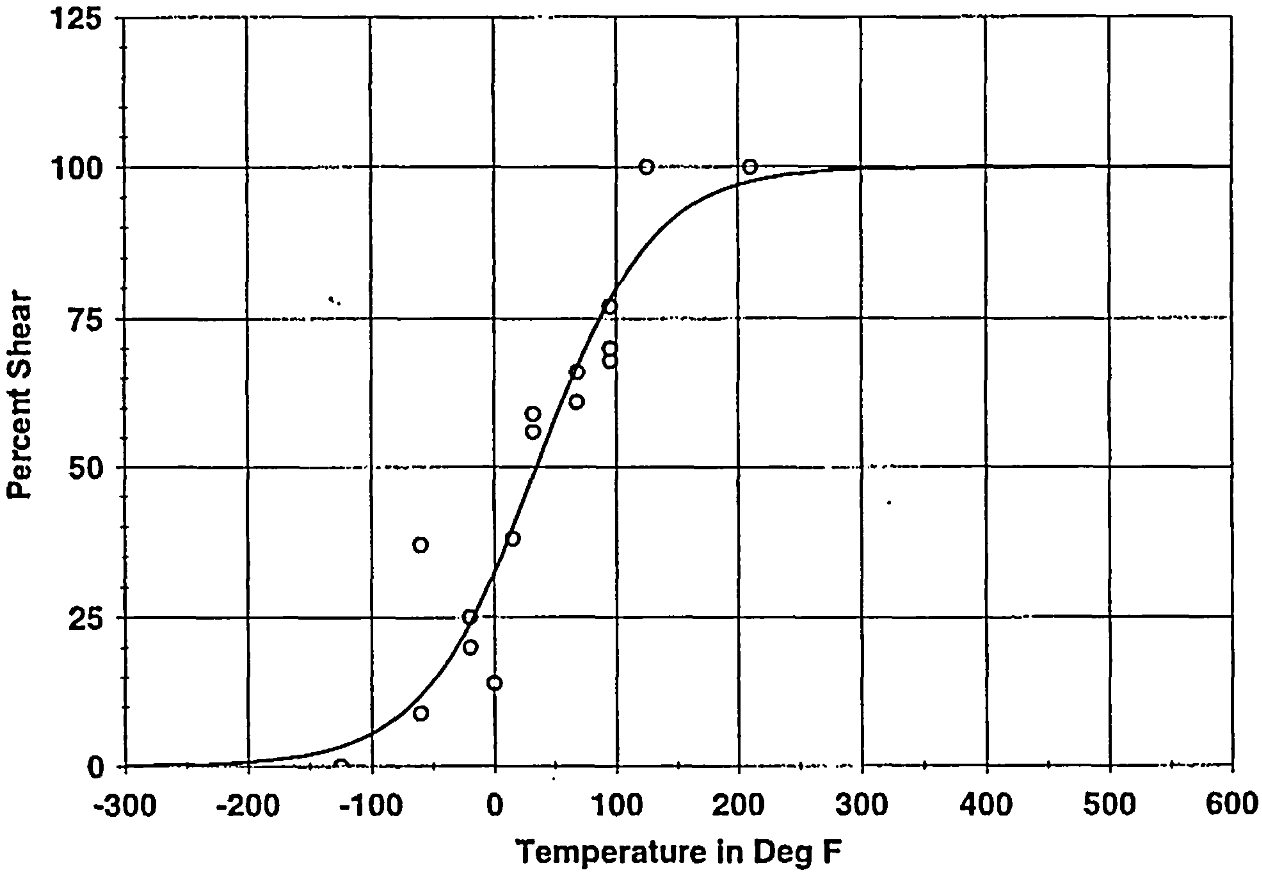
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
68.00	65.00	65.85	-.85
68.00	66.00	65.85	.15
95.00	78.00	71.86	6.14
95.00	54.00	71.86	-17.86
95.00	69.00	71.86	-2.86
125.00	80.00	75.89	4.11
125.00	88.00	75.89	12.11
210.00	77.00	79.81	-2.81
210.00	79.00	79.81	-.81

Correlation Coefficient = .958

UNIRRADIATED INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/06/2004 02:00 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 94.86 T0 = 34.78 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 34.8
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: UNIRR Fluence: 0.0 n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-125.00	.00	3.33	-3.33
-60.00	37.00	11.94	25.06
-60.00	9.00	11.94	-2.94
-20.00	20.00	23.96	-3.96
-20.00	25.00	23.96	1.04
.00	14.00	32.45	-18.45
15.00	38.00	39.72	-1.72
32.00	56.00	48.53	7.47
32.00	59.00	48.53	10.47

UNIRRADIATED INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: UNIRR Fluence: 0.0 n/cm^2

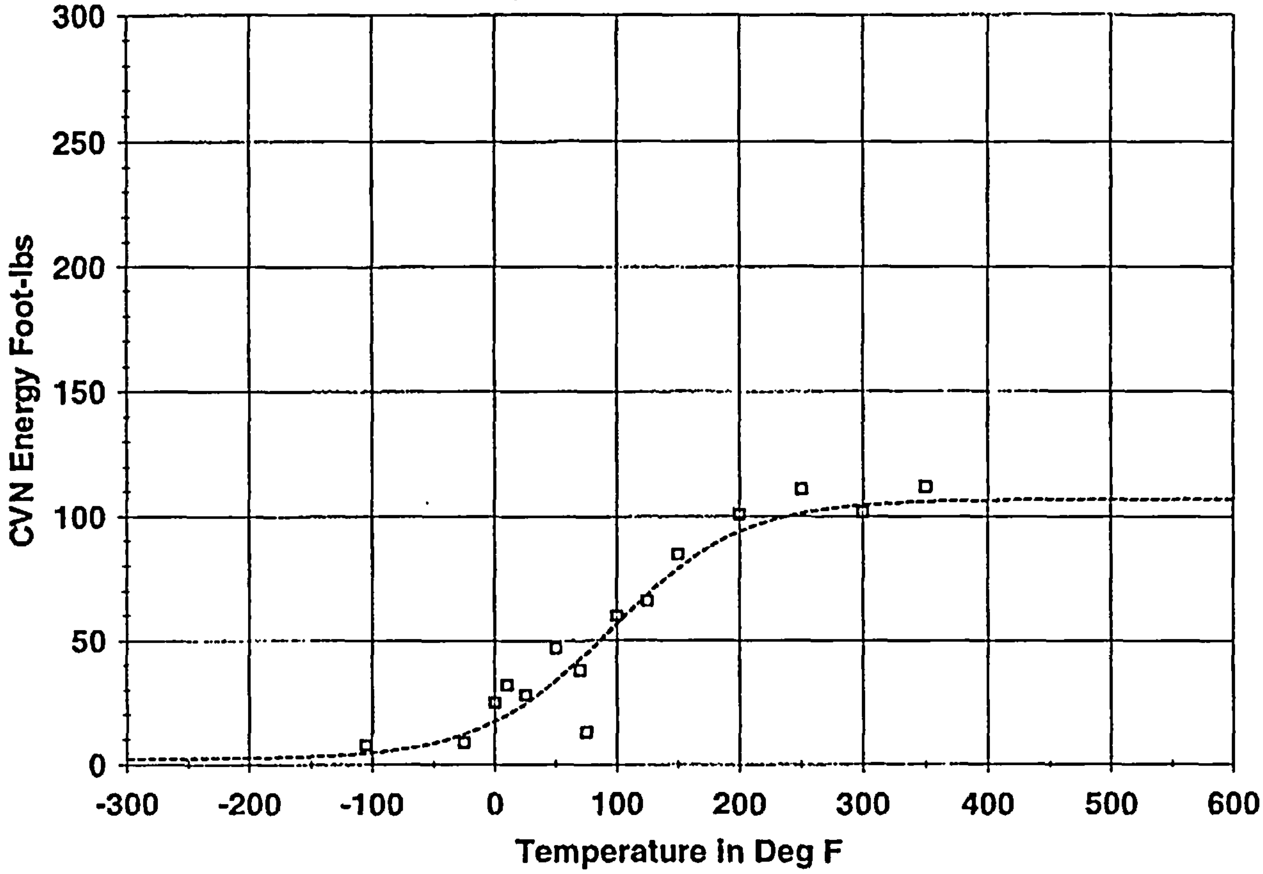
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
68.00	61.00	66.83	-5.83
68.00	66.00	66.83	-.83
95.00	77.00	78.07	-1.07
95.00	70.00	78.07	-8.07
95.00	68.00	78.07	-10.07
125.00	100.00	87.01	12.99
125.00	100.00	87.01	12.99
210.00	100.00	97.57	2.43
210.00	100.00	97.57	2.43

Correlation Coefficient = .953

CAPSULE U INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/06/2004 11:07 AM
Page 1
Coefficients of Curve 2
A = 54.6 B = 52.4 C = 107.38 T0 = 95.83 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=107.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=41.2 Deg F Temp@50 ft-lbs=86.4 Deg F
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: U Fluence: 0.0 n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-105.00	8.00	4.63	3.37
-25.00	9.00	12.19	-3.19
.00	25.00	17.26	7.74
10.00	32.00	19.83	12.17
25.00	28.00	24.31	3.69
50.00	47.00	33.50	13.50
70.00	38.00	42.23	-4.23
75.00	13.00	44.56	-31.56
100.00	60.00	56.64	3.36

CAPSULE U INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: U Fluence: 0.0 n/cm^2

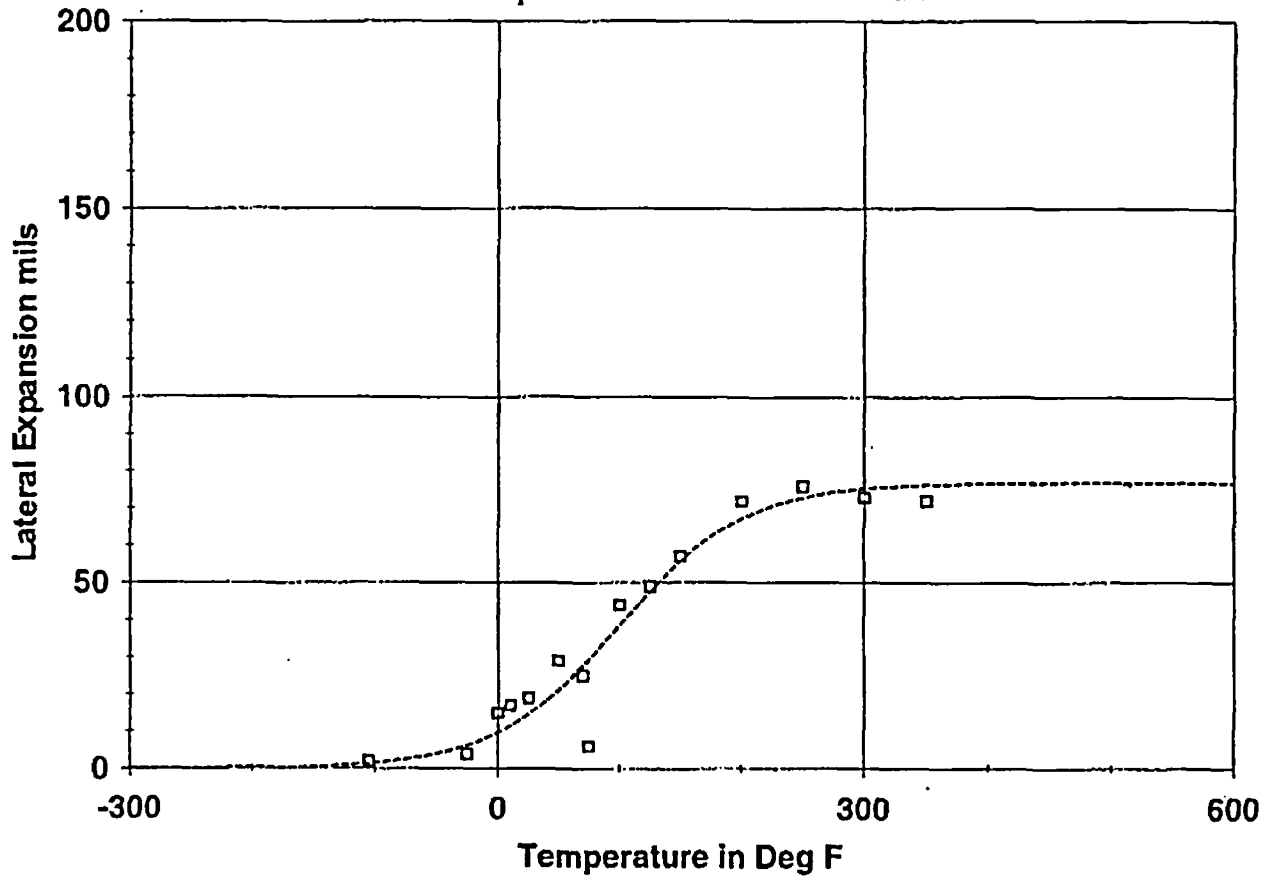
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
125.00	66.00	68.50	-2.50
150.00	85.00	79.00	6.00
200.00	101.00	93.83	7.17
250.00	111.00	101.38	9.62
300.00	102.00	104.71	-2.71
350.00	112.00	106.09	5.91

Correlation Coefficient = .959

CAPSULE U INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/06/2004 02:08 PM
Page 1
Coefficients of Curve 2
A = 38.44 B = 38.44 C = 103.11 T0 = 100.22 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=76.9 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=91.0 Deg F
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: U Fluence: 0.0 n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-105.00	2.00	1.41	.59
-25.00	4.00	6.23	-2.23
.00	15.00	9.63	5.37
10.00	17.00	11.38	5.62
25.00	19.00	14.50	4.50
50.00	29.00	21.07	7.93
70.00	25.00	27.49	-2.49
75.00	6.00	29.22	-23.22
100.00	44.00	38.36	5.64

CAPSULE U INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: U Fluence: 0.0 n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
125.00	49.00	47.50	1.50
150.00	57.00	55.68	1.32
200.00	72.00	67.18	4.82
250.00	76.00	72.89	3.11
300.00	73.00	75.31	-2.31
350.00	72.00	76.28	-4.28

Correlation Coefficient = .962

CAPSULE U INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/06/2004 02:00 PM

Page 1

Coefficients of Curve 2

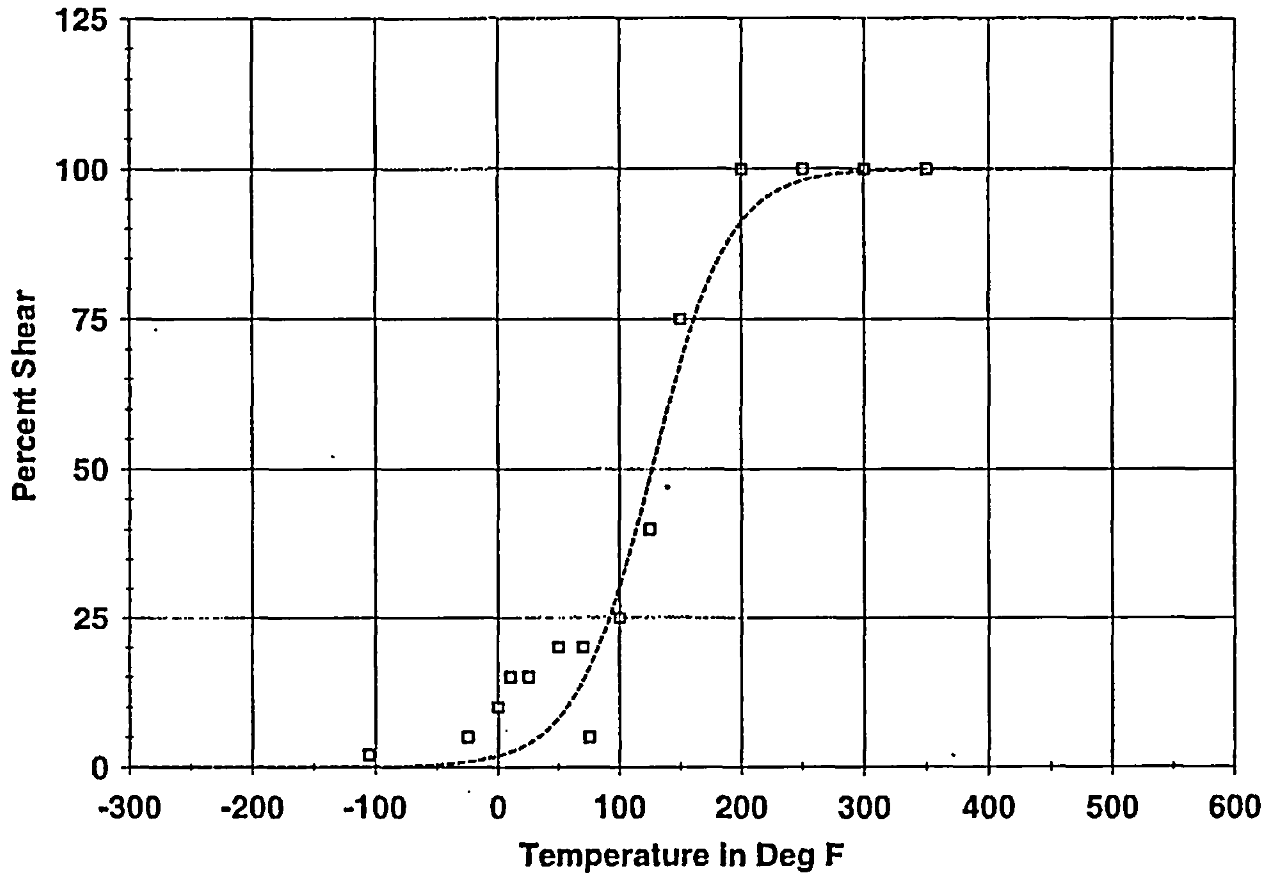
A = 50. B = 50. C = 63.23 T0 = 126.56 D = 0.00E+00

Equation is A + B * [Tanh((T-To)/(C+DT))]

Temperature at 50% Shear = 126.6

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536

Orientation: LT Capsule: U Fluence: 0.0 n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-105.00	2.00	.07	1.93
-25.00	5.00	.82	4.18
.00	10.00	1.79	8.21
10.00	15.00	2.44	12.56
25.00	15.00	3.87	11.13
50.00	20.00	8.15	11.85
70.00	20.00	14.32	5.68
75.00	5.00	16.37	-11.37
100.00	25.00	30.15	-5.15

CAPSULE U INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: U Fluence: 0.0 n/cm^2

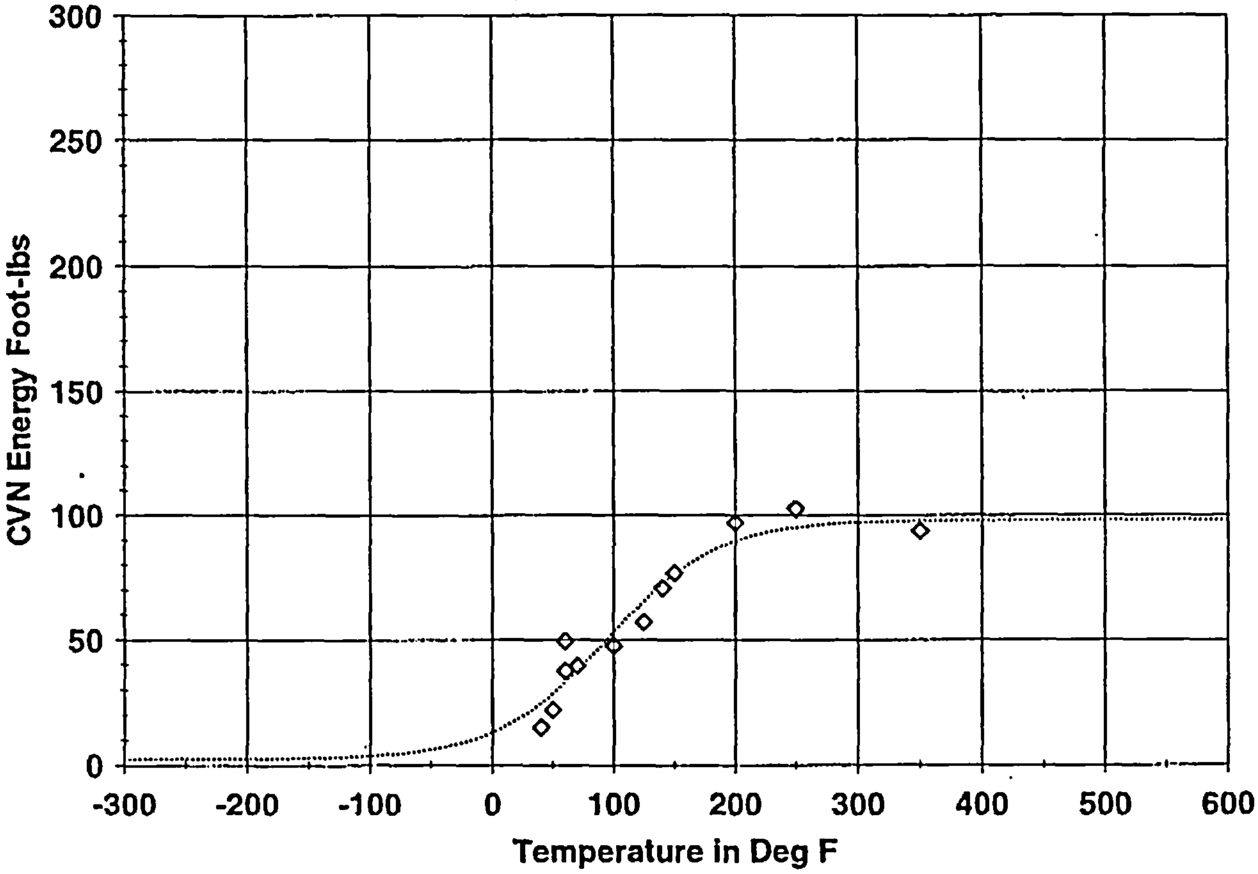
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
125.00	40.00	48.77	-8.77
150.00	75.00	67.73	7.27
200.00	100.00	91.08	8.92
250.00	100.00	98.02	1.98
300.00	100.00	99.59	.41
350.00	100.00	99.91	.09

Correlation Coefficient = .984

CAPSULE W INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/06/2004 11:07 AM
Page 1
Coefficients of Curve 3
A = 50.1 B = 47.9 C = 91.41 T0 = 95.16 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=98.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=54.3 Deg F Temp@50 ft-lbs=95.0 Deg F
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
40.00	15.00	24.26	-9.26
50.00	22.00	28.19	-6.19
60.00	37.50	32.53	4.97
60.00	49.50	32.53	16.97
70.00	39.50	37.24	2.26
100.00	47.50	52.63	-5.13
125.00	57.00	65.20	-8.20
140.00	70.50	71.88	-1.38
150.00	76.50	75.82	.68

CAPSULE W INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: W Fluence: n/cm^2

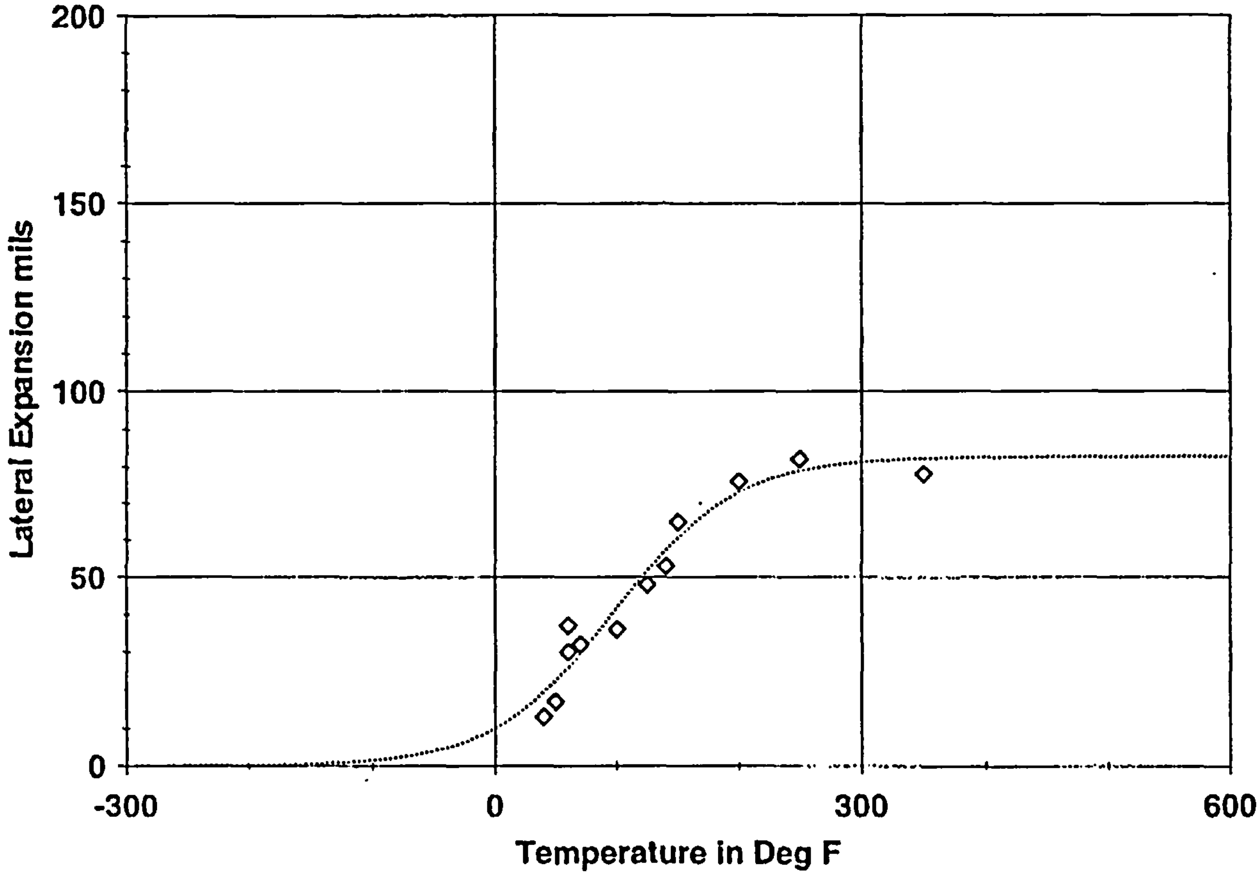
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
200.00	97.00	89.22	7.78
250.00	102.50	94.87	7.63
350.00	93.50	97.64	-4.14

Correlation Coefficient = .964

CAPSULE W INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/06/2004 02:08 PM
Page 1
Coefficients of Curve 3
A = 41.32 B = 41.32 C = 99.72 T0 = 99.66 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=82.6 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=84.3 Deg F
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
40.00	13.00	19.18	-6.18
50.00	17.00	22.29	-5.29
60.00	30.00	25.70	4.30
60.00	37.00	25.70	11.30
70.00	32.00	29.38	2.62
100.00	36.00	41.46	-5.46
125.00	48.00	51.60	-3.60
140.00	53.00	57.18	-4.18
150.00	65.00	60.58	4.42

CAPSULE W INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: W Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
200.00	76.00	72.90	3.10
250.00	82.00	78.78	3.22
350.00	78.00	82.11	-4.11

Correlation Coefficient = .972

CAPSULE W INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/06/2004 02:01 PM

Page 1

Coefficients of Curve 3

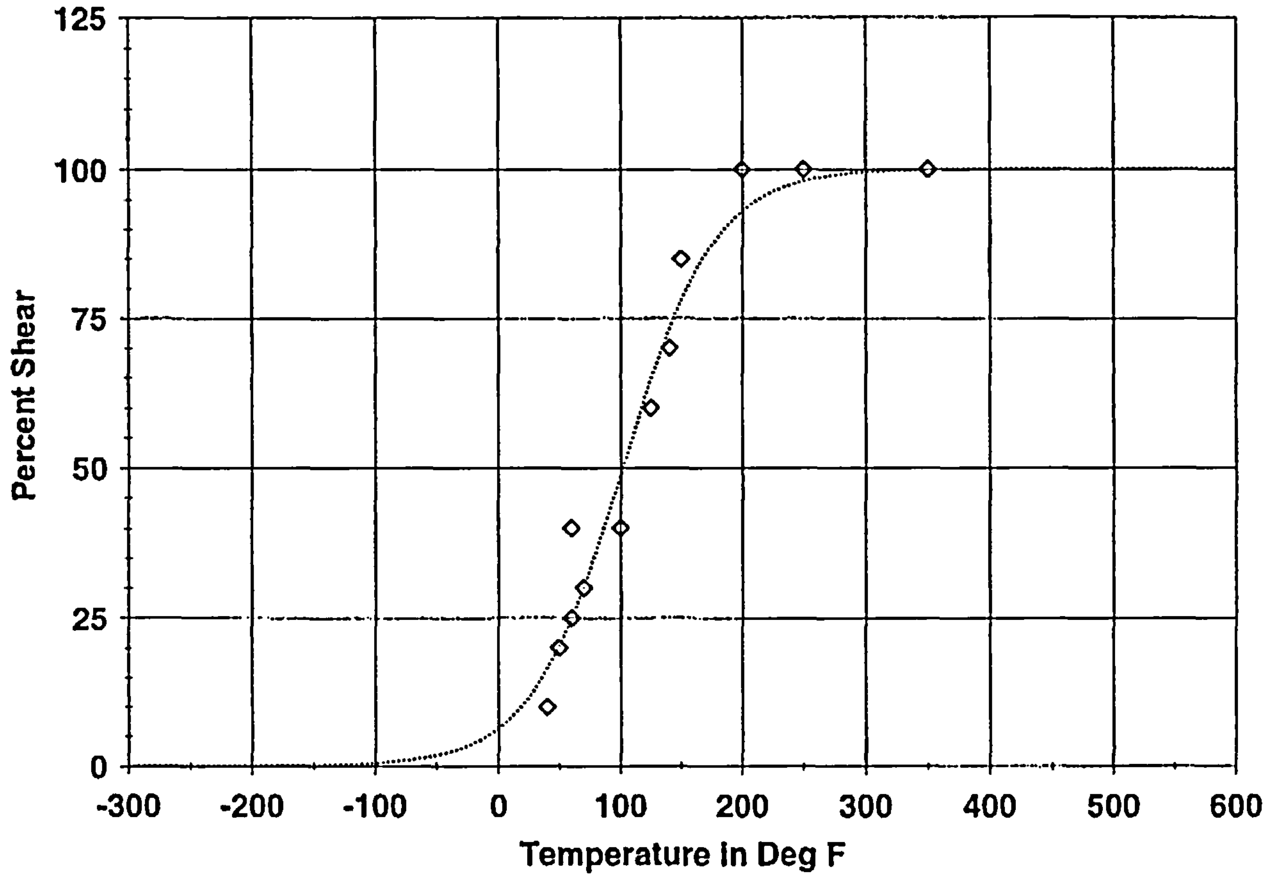
A = 50. B = 50. C = 75.89 T0 = 102.25 D = 0.00E+00

Equation is A + B * [Tanh((T-To)/(C+DT))]

Temperature at 50% Shear = 102.3

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536

Orientation: LT Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
40.00	10.00	16.24	-6.24
50.00	20.00	20.15	-.15
60.00	25.00	24.73	.27
60.00	40.00	24.73	15.27
70.00	30.00	29.95	.05
100.00	40.00	48.52	-8.52
125.00	60.00	64.56	-4.56
140.00	70.00	73.01	-3.01
150.00	85.00	77.88	7.12

CAPSULE W INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: W Fluence: n/cm^2

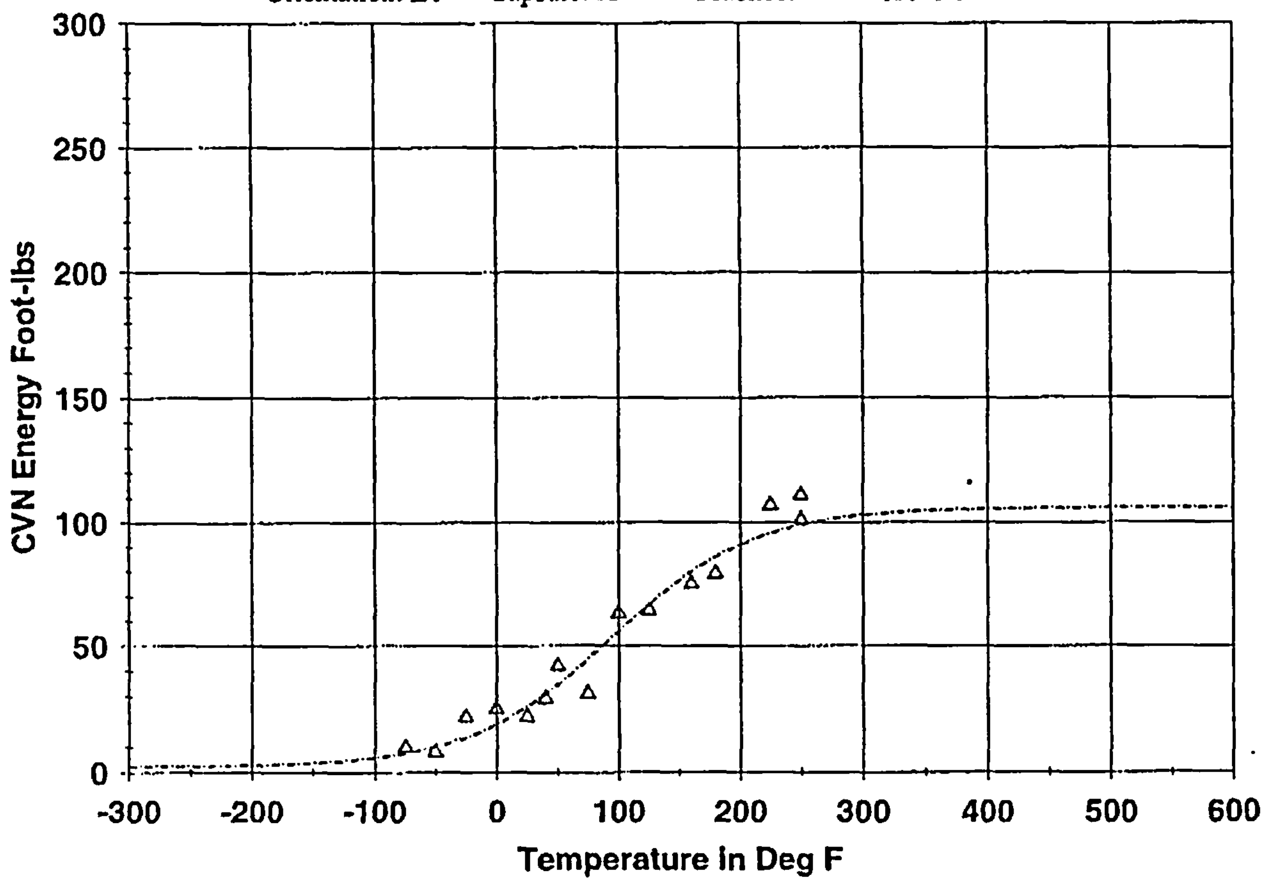
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
200.00	100.00	92.93	7.07
250.00	100.00	98.00	2.00
350.00	100.00	99.85	.15

Correlation Coefficient = .981

CAPSULE X INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/06/2004 11:07 AM
Page 1
Coefficients of Curve 4
A = 54.1 B = 51.9 C = 117.15 T0 = 96.42 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=106.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=37.6 Deg F Temp@50 ft-lbs=87.2 Deg F
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-75.00	10.00	7.48	2.52
-50.00	8.00	10.08	-2.08
-25.00	22.00	13.80	8.20
.00	25.00	18.98	6.02
25.00	22.00	25.87	-3.87
40.00	29.00	30.87	-1.87
50.00	42.00	34.55	7.45
75.00	31.00	44.71	-13.71
100.00	63.00	55.69	7.31

CAPSULE X INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: X Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
125.00	64.00	66.52	-2.52
160.00	75.00	79.79	-4.79
180.00	79.00	85.91	-6.91
225.00	107.00	95.60	11.40
250.00	101.00	98.97	2.03
250.00	111.00	98.97	12.03

Correlation Coefficient = .979

CAPSULE X INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/06/2004 02:08 PM

Page 1

Coefficients of Curve 4

A = 41.57 B = 41.57 C = 138.42 T0 = 128.58 D = 0.00E+00

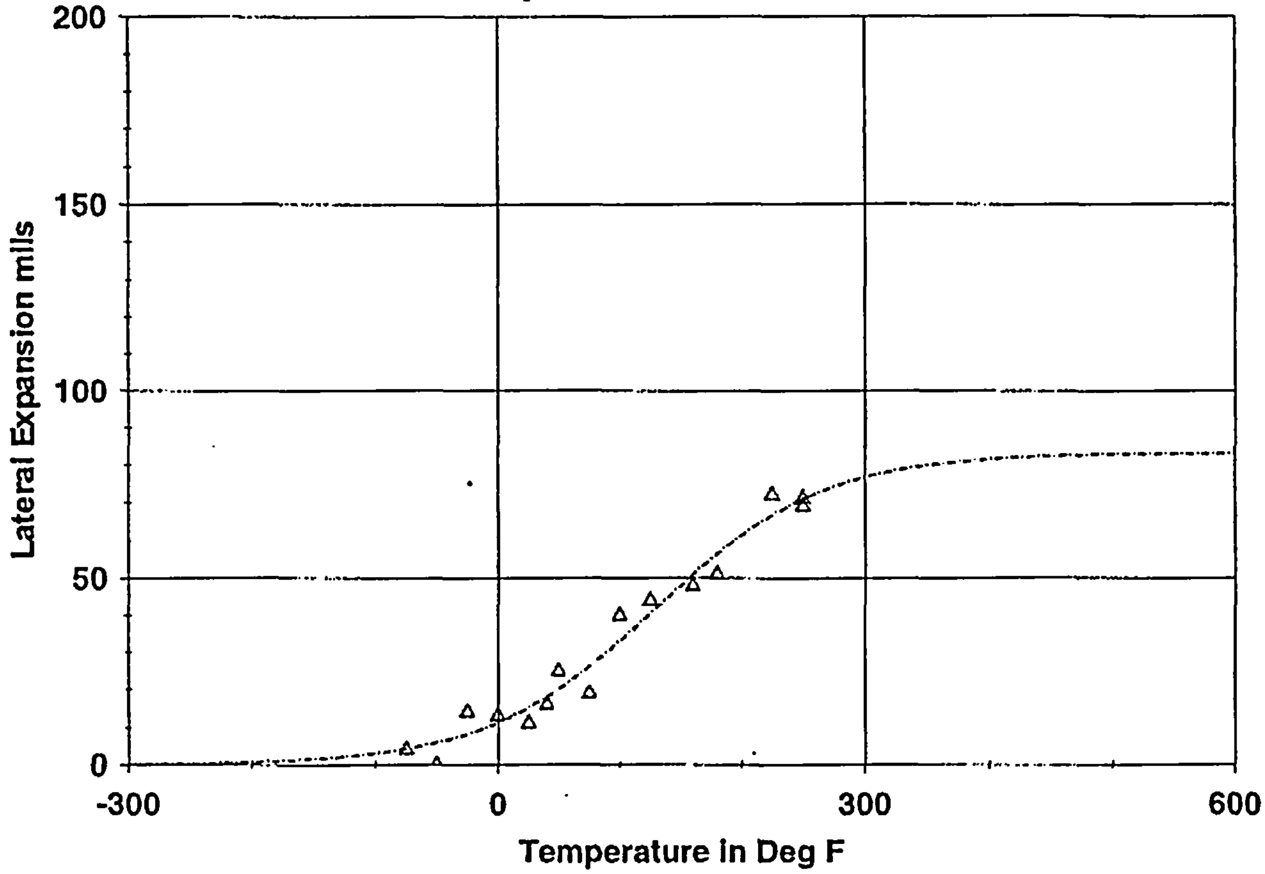
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=83.1 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=106.6 Deg F

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536

Orientation: LT Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-75.00	4.00	4.17	-.17
-50.00	.00	5.85	-5.85
-25.00	14.00	8.15	5.85
.00	13.00	11.22	1.78
25.00	11.00	15.21	-4.21
40.00	16.00	18.09	-2.09
50.00	25.00	20.22	4.78
75.00	19.00	26.24	-7.24
100.00	40.00	33.10	6.90

CAPSULE X INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: X Fluence: n/cm^2

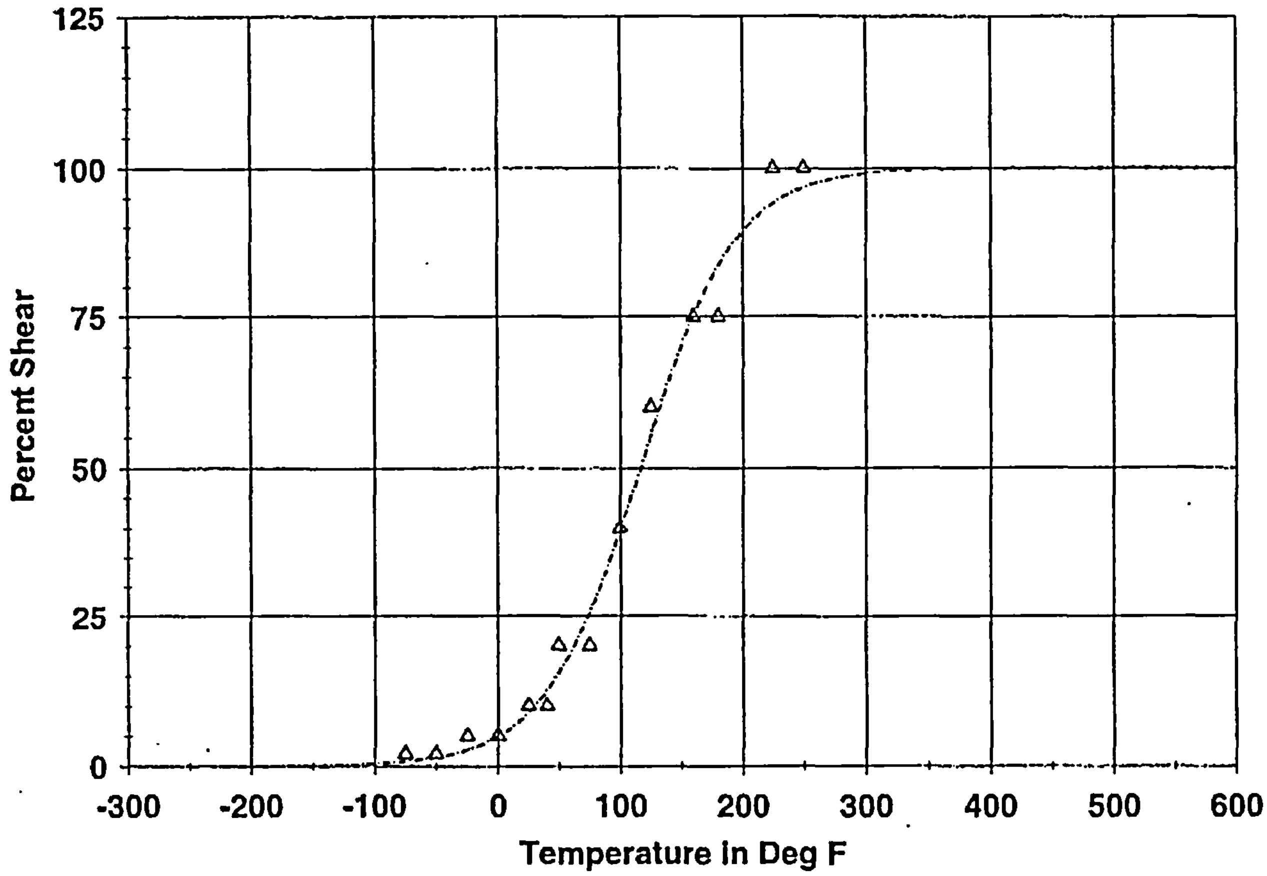
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
125.00	44.00	40.49	3.51
160.00	48.00	50.84	-2.84
180.00	51.00	56.33	-5.33
225.00	72.00	66.60	5.40
250.00	69.00	70.87	-1.87
250.00	71.00	70.87	.13

Correlation Coefficient = .983

CAPSULE X INTERMEDIATE SHELL 05 (TANGENTIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/06/2004 02:01 PM
Page 1
Coefficients of Curve 4
A = 50. B = 50. C = 78.4 T0 = 116.58 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 116.6
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-75.00	2.00	.75	1.25
-50.00	2.00	1.41	.59
-25.00	5.00	2.63	2.37
.00	5.00	4.86	.14
25.00	10.00	8.82	1.18
40.00	10.00	12.42	-2.42
50.00	20.00	15.47	4.53
75.00	20.00	25.72	-5.72
100.00	40.00	39.58	.42

CAPSULE X INTERMEDIATE SHELL 05 (TANGENTIAL)

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: LT Capsule: X Fluence: n/cm^2

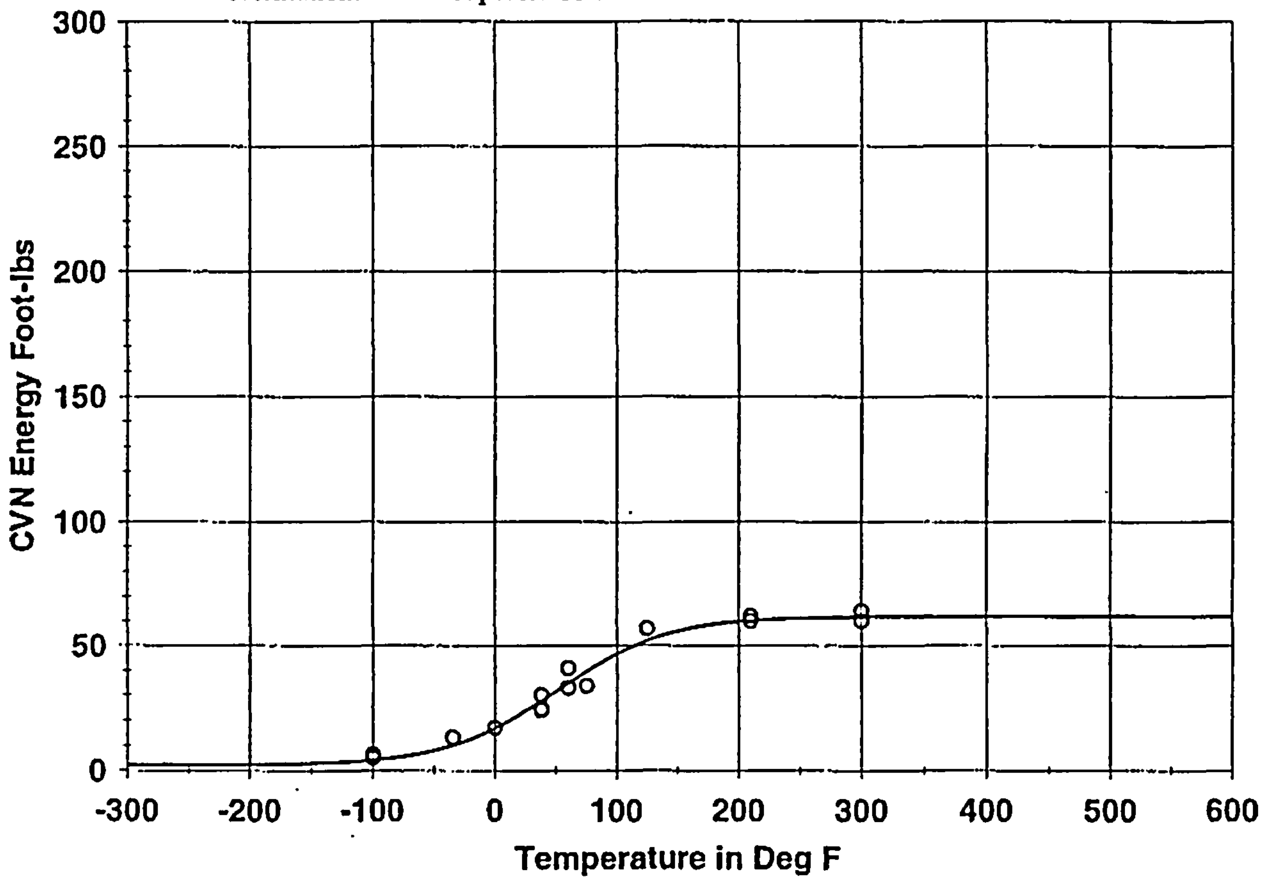
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
125.00	60.00	55.35	4.65
160.00	75.00	75.17	-.17
180.00	75.00	83.45	-8.45
225.00	100.00	94.08	5.92
250.00	100.00	96.78	3.22
250.00	100.00	96.78	3.22

Correlation Coefficient = .995

UNIRRADIATED INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 09:56 AM
Page 1
Coefficients of Curve 1
A = 32.1 B = 29.9 C = 90.57 T0 = 51.57 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=62.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=45.2 Deg F Temp@50 ft-lbs=114.2 Deg F
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: UNIRR Fluence: 0.0 n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-100.00	5.50	4.23	1.27
-100.00	5.00	4.23	.77
-100.00	6.50	4.23	2.27
-35.00	13.00	9.90	3.10
.00	17.00	16.70	.30
.00	17.00	16.70	.30
38.00	24.50	27.65	-3.15
38.00	30.00	27.65	2.35
38.00	24.00	27.65	-3.65

UNIRRADIATED INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: UNIRR Fluence: 0.0 n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
60.00	41.00	34.88	6.12
60.00	33.00	34.88	-1.88
75.00	34.00	39.67	-5.67
125.00	57.00	52.13	4.87
210.00	62.00	60.24	1.76
210.00	62.00	60.24	1.76
210.00	60.00	60.24	-.24
300.00	60.00	61.75	-1.75
300.00	64.00	61.75	2.25

Correlation Coefficient = .991

UNIRRADIATED INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 10:42 AM

Page 1

Coefficients of Curve 1

A = 29.17 B = 29.17 C = 101.37 T0 = 63.98 D = 0.00E+00

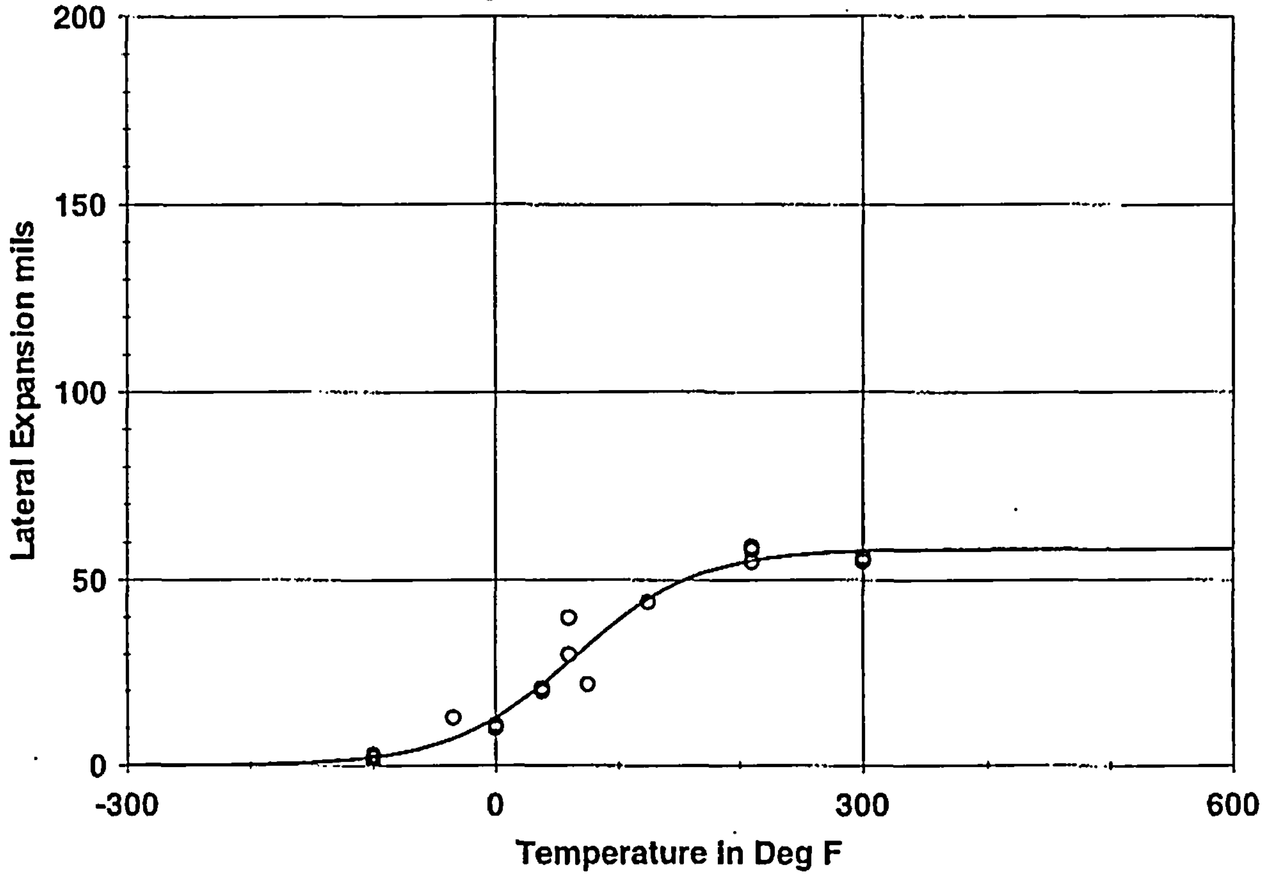
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=58.3 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=84.6 Deg F

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536

Orientation: TL Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-100.00	2.00	2.21	-.21
-100.00	1.00	2.21	-1.21
-100.00	3.00	2.21	.79
-35.00	13.00	7.25	5.75
.00	11.00	12.87	-1.87
.00	10.00	12.87	-2.87
38.00	21.00	21.85	-.85
38.00	21.00	21.85	-.85
38.00	20.00	21.85	-1.85

UNIRRADIATED INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
60.00	40.00	28.03	11.97
60.00	30.00	28.03	1.97
75.00	22.00	32.33	-10.33
125.00	44.00	44.88	-.88
210.00	58.00	55.24	2.76
210.00	59.00	55.24	3.76
210.00	55.00	55.24	-.24
300.00	55.00	57.79	-2.79
300.00	56.00	57.79	-1.79

Correlation Coefficient = .977

UNIRRADIATED INTERMEDIATE SHELL PLATE 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 10:26 AM

Page 1

Coefficients of Curve 1

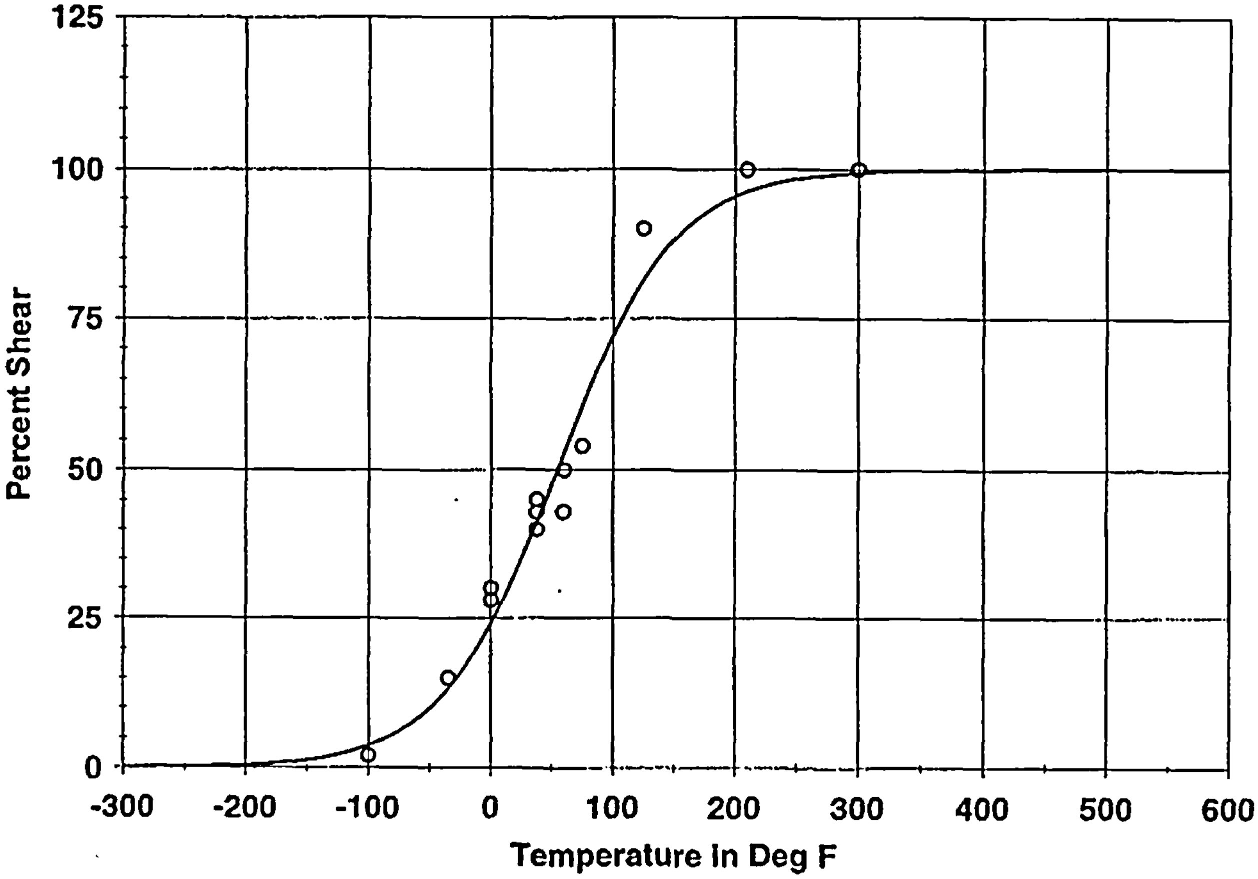
A = 50. B = 50. C = 95.2 T0 = 54.88 D = 0.00E+00

Equation is A + B * [Tanh((T-To)/(C+DT))]

Temperature at 50% Shear = 54.9

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536

Orientation: TL Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100.00	2.00	3.72	-1.72
-100.00	2.00	3.72	-1.72
-100.00	2.00	3.72	-1.72
-35.00	15.00	13.14	1.86
.00	30.00	23.99	6.01
.00	28.00	23.99	4.01
38.00	45.00	41.22	3.78
38.00	43.00	41.22	1.78
38.00	40.00	41.22	-1.22

UNIRRADIATED INTERMEDIATE SHELL PLATE 05 (AXIAL)

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: UNIRR Fluence: n/cm^2

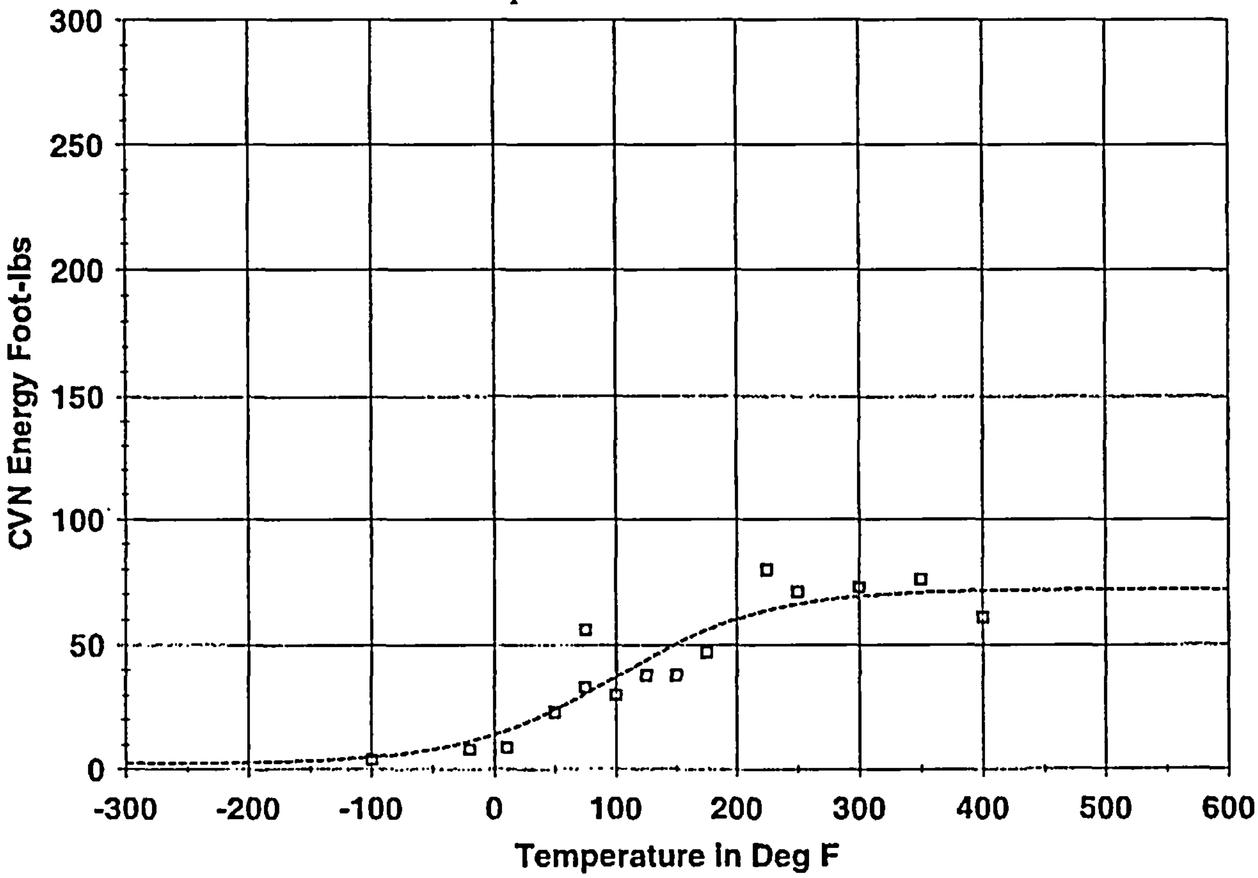
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
60.00	50.00	52.68	-2.68
60.00	43.00	52.68	-9.68
75.00	54.00	60.41	-6.41
125.00	90.00	81.35	8.65
210.00	100.00	96.30	3.70
210.00	100.00	96.30	3.70
210.00	100.00	96.30	3.70
300.00	100.00	99.42	.58
300.00	100.00	99.42	.58

Correlation Coefficient = .993

CAPSULE U INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 09:56 AM
Page 1
Coefficients of Curve 2
A = 37.1 B = 34.9 C = 125.83 T0 = 99.81 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=72.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=73.9 Deg F Temp@50 ft-lbs=148.7 Deg F
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: U Fluence: 0.0 n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-100.00	4.00	5.00	-1.00
-20.00	8.00	11.25	-3.25
10.00	9.00	15.71	-6.71
50.00	23.00	23.96	-.96
75.00	33.00	30.31	2.69
75.00	56.00	30.31	25.69
100.00	30.00	37.15	-7.15
125.00	38.00	43.99	-5.99
150.00	38.00	50.33	-12.33

CAPSULE U INTERMEDIATE SHELL 05 (AXIAL)

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: U Fluence: 0.0 n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
175.00	47.00	55.78	-8.78
225.00	80.00	63.60	16.40
250.00	71.00	66.13	4.87
300.00	73.00	69.22	3.78
350.00	76.00	70.72	5.28
400.00	61.00	71.41	-10.41

Correlation Coefficient = .917

CAPSULE U INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 10:43 AM

Page 1

Coefficients of Curve 2

A = 28.65 B = 28.65 C = 111.9 T0 = 88.09 D = 0.00E+00

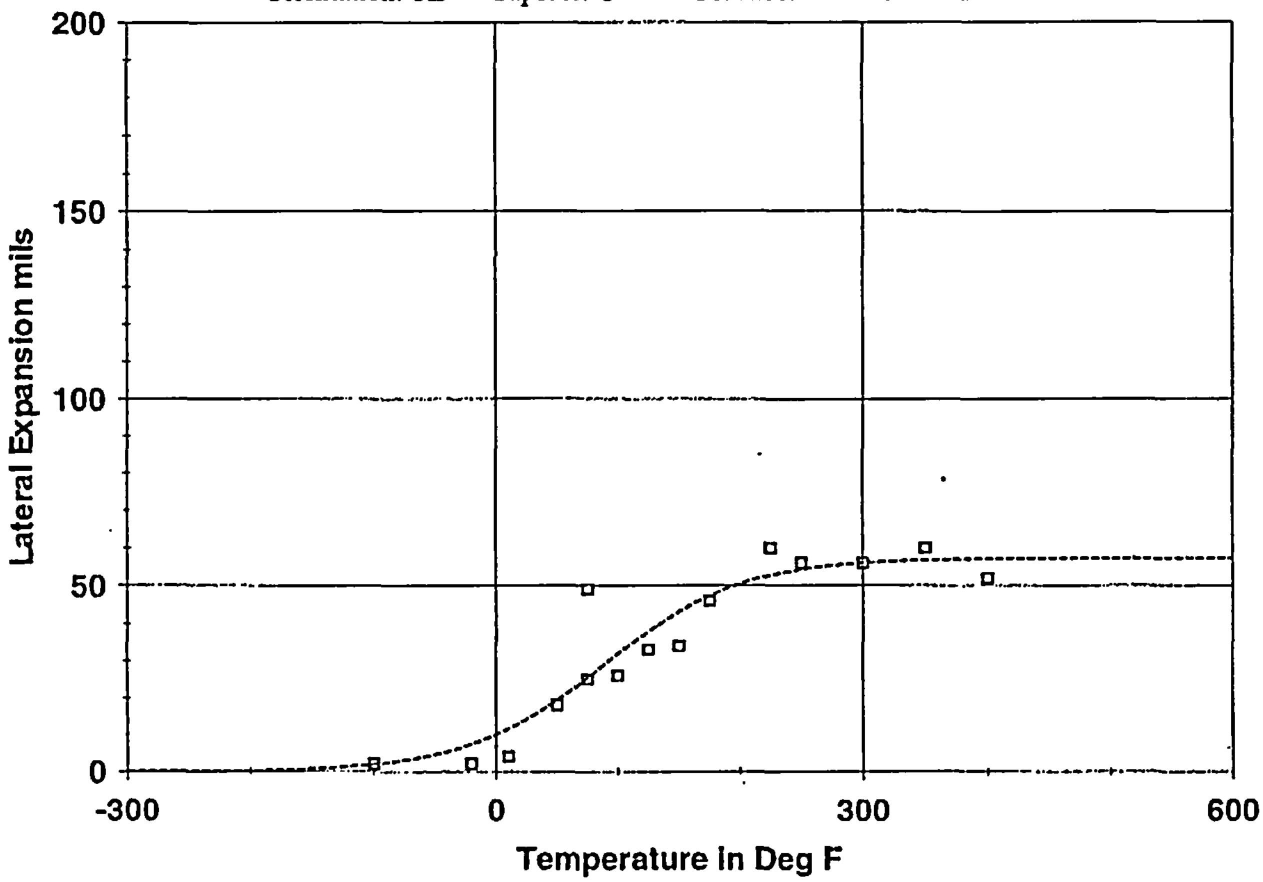
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=57.3 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=113.4 Deg F

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536

Orientation: TL Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-100.00	2.00	1.92	.08
-20.00	2.00	7.25	-5.25
10.00	4.00	11.37	-7.37
50.00	18.00	19.26	-1.26
75.00	25.00	25.32	-.32
75.00	49.00	25.32	23.68
100.00	26.00	31.69	-5.69
125.00	33.00	37.77	-4.77
150.00	34.00	43.06	-9.06

CAPSULE U INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: U Fluence: n/cm^2

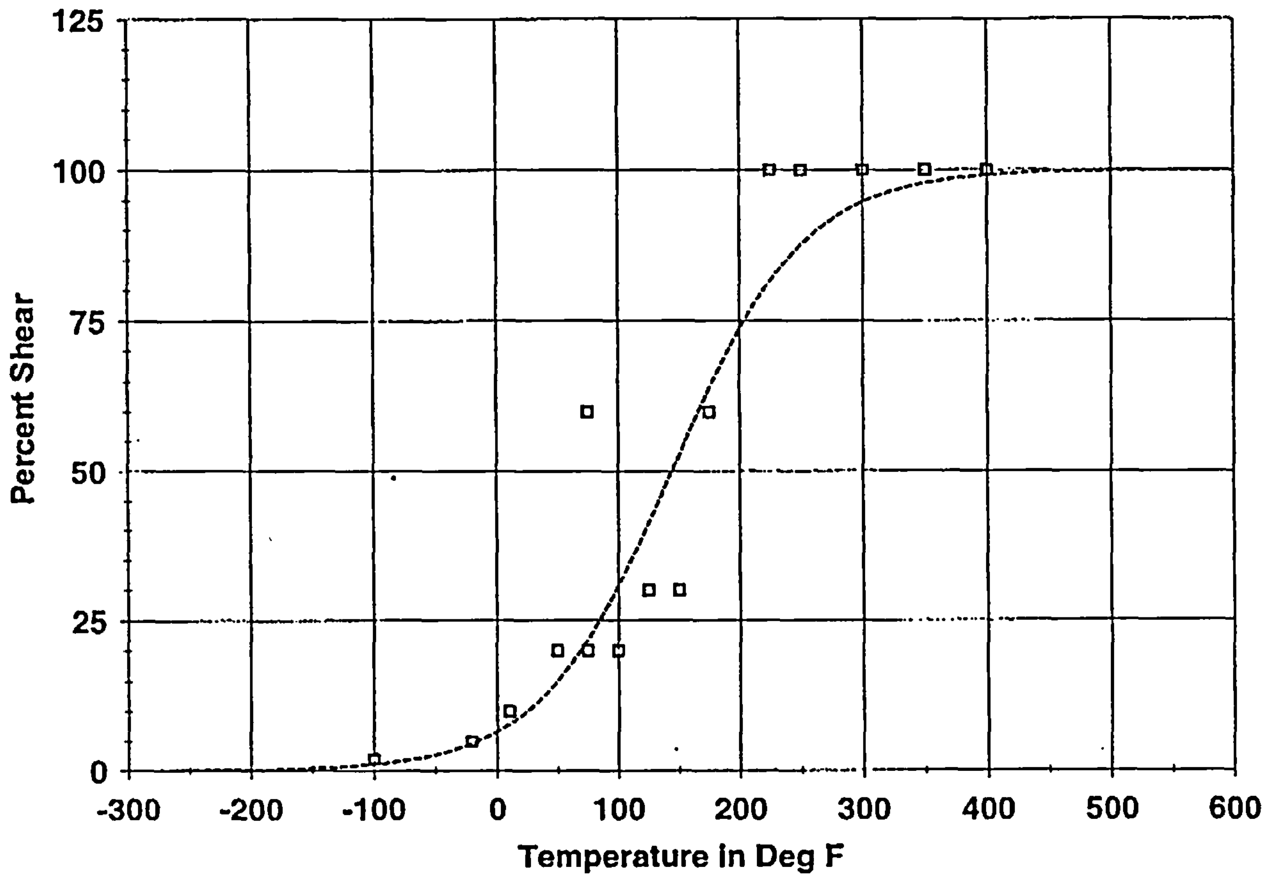
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
175.00	46.00	47.30	-1.30
225.00	60.00	52.74	7.26
250.00	56.00	54.30	1.70
300.00	56.00	56.03	-.03
350.00	60.00	56.78	3.22
400.00	52.00	57.09	-5.09

Correlation Coefficient = .929

CAPSULE U INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 10:26 AM
Page 1
Coefficients of Curve 2
A = 50. B = 50. C = 108.6 T0 = 144.29 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 144.3
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100.00	2.00	1.10	.90
-20.00	5.00	4.63	.37
10.00	10.00	7.78	2.22
50.00	20.00	14.98	5.02
75.00	20.00	21.82	-1.82
75.00	60.00	21.82	38.18
100.00	20.00	30.67	-10.67
125.00	30.00	41.21	-11.21
150.00	30.00	52.63	-22.63

CAPSULE U INTERMEDIATE SHELL 05 (AXIAL)

Page 2

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536

Orientation: TL Capsule: U Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
175.00	60.00	63.77	-3.77
225.00	100.00	81.55	18.45
250.00	100.00	87.51	12.49
300.00	100.00	94.62	5.38
350.00	100.00	97.79	2.21
400.00	100.00	99.11	.89

Correlation Coefficient = .937

CAPSULE X INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 09:56 AM

Page 1

Coefficients of Curve 4

A = 34.1 B = 31.9 C = 84.5 T0 = 172. D = 0.00E+00

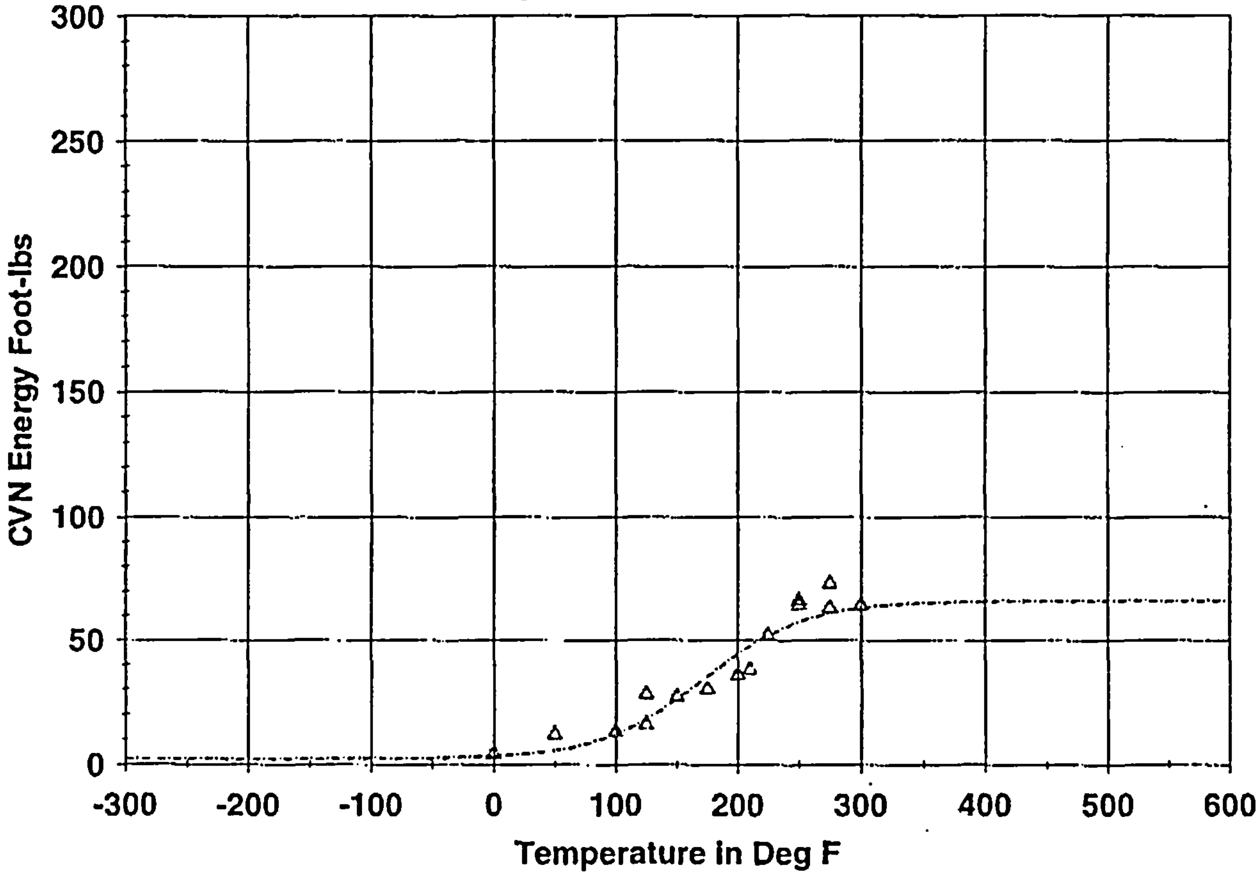
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=66.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=161.1 Deg F Temp@50 ft-lbs=218.3 Deg F

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536

Orientation: TL Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
.00	4.00	3.27	.73
50.00	12.00	5.57	6.43
100.00	13.00	12.02	.98
125.00	28.00	17.99	10.01
125.00	16.00	17.99	-1.99
150.00	27.00	25.98	1.02
175.00	30.00	35.23	-5.23
200.00	36.00	44.30	-8.30
210.00	38.00	47.55	-9.55

CAPSULE X INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: X Fluence: n/cm^2

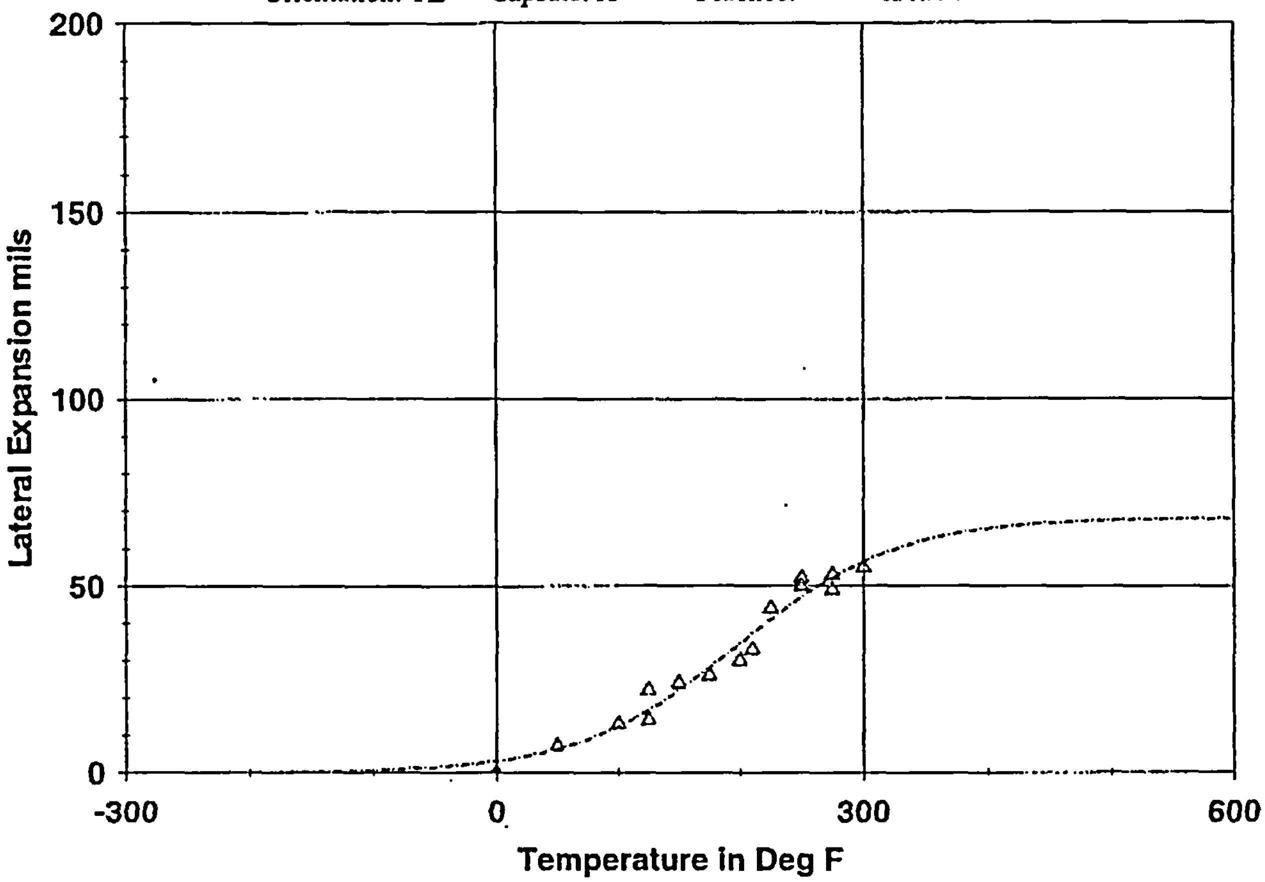
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
225.00	52.00	51.84	.16
250.00	66.00	57.30	8.70
250.00	64.00	57.30	6.70
275.00	73.00	60.87	12.13
275.00	63.00	60.87	2.13
300.00	64.00	63.06	.94

Correlation Coefficient = .961

CAPSULE X INTERMEDIATE 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 10:43 AM
Page 1
Coefficients of Curve 4
A = 34.07 B = 34.07 C = 129.63 T0 = 197.99 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=68.1 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=201.6 Deg F
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
.00	.00	3.07	-3.07
50.00	7.00	6.30	.70
100.00	13.00	12.31	.69
125.00	22.00	16.69	5.31
125.00	14.00	16.69	-2.69
150.00	24.00	22.00	2.00
175.00	26.00	28.09	-2.09
200.00	30.00	34.60	-4.60
210.00	33.00	37.22	-4.22

CAPSULE X INTERMEDIATE 05 (AXIAL)

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: X Fluence: n/cm^2

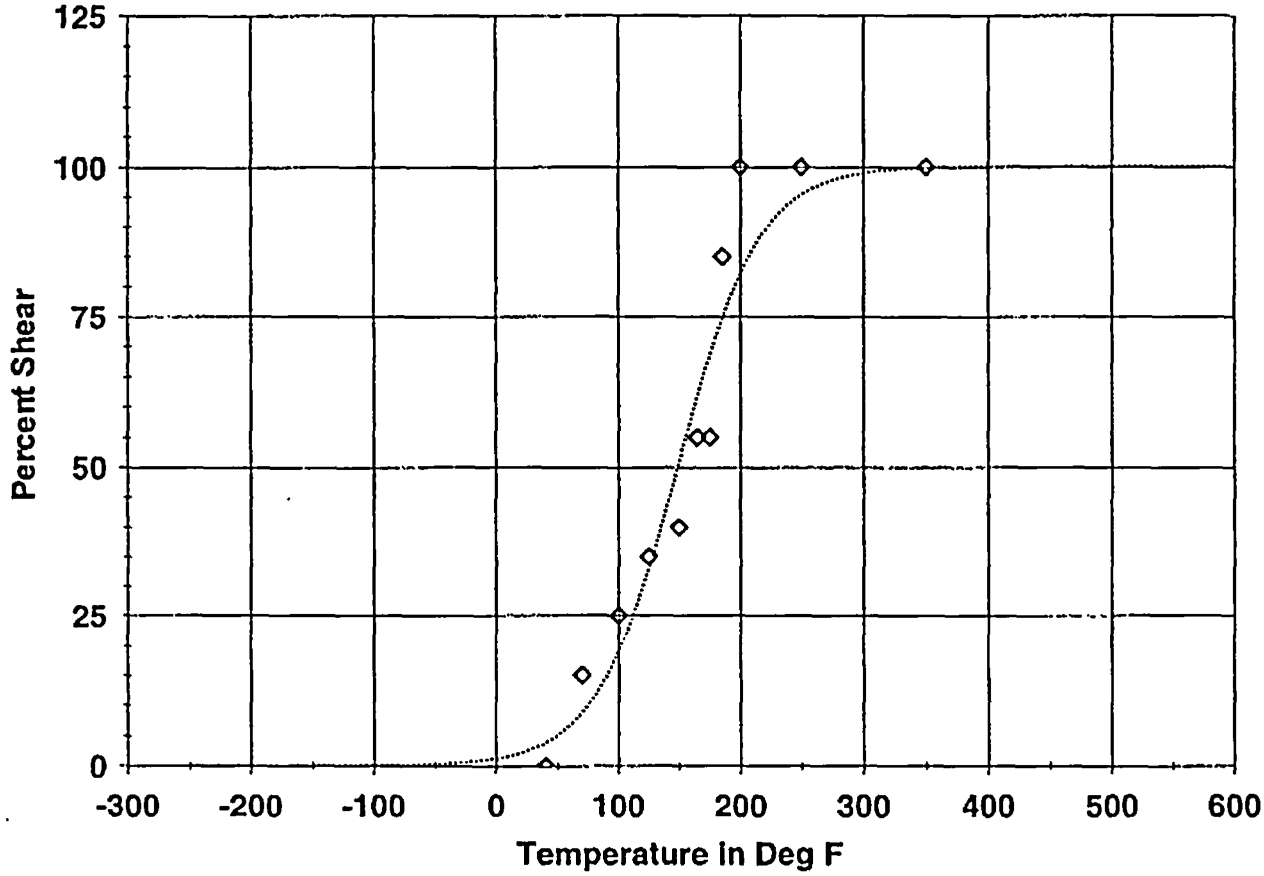
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
225.00	44.00	41.07	2.93
250.00	50.00	47.05	2.95
250.00	52.00	47.05	4.95
275.00	53.00	52.22	.78
275.00	49.00	52.22	-3.22
300.00	55.00	56.44	-1.44

Correlation Coefficient = .984

CAPSULE W INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 10:26 AM
Page 1
Coefficients of Curve 3
A = 50. B = 50. C = 66.93 T0 = 149.07 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 149.1
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
40.00	.00	3.70	-3.70
70.00	15.00	8.60	6.40
70.00	15.00	8.60	6.40
100.00	25.00	18.75	6.25
125.00	35.00	32.75	2.25
150.00	40.00	50.69	-10.69
165.00	55.00	61.68	-6.68
175.00	55.00	68.45	-13.45
185.00	85.00	74.53	10.47

CAPSULE W INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: W Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
200.00	100.00	82.08	17.92
250.00	100.00	95.33	4.67
350.00	100.00	99.75	.25

Correlation Coefficient = .969

CAPSULE W INTERMEDIATE SHELL 05

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 09:56 AM

Page 1

Coefficients of Curve 3

A = 31.1 B = 28.9 C = 99.98 T0 = 127.92 D = 0.00E+00

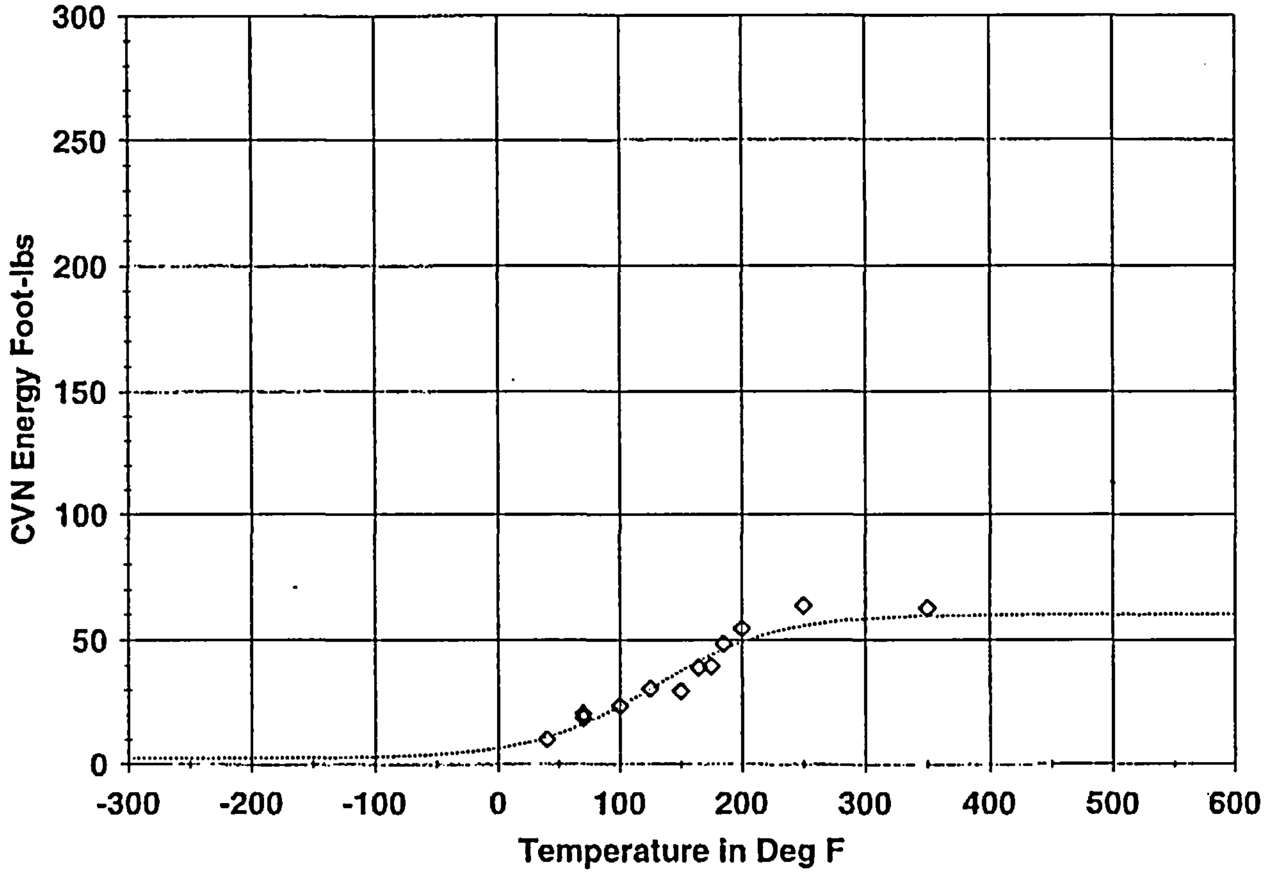
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=60.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=124.2 Deg F Temp@50 ft-lbs=206.2 Deg F

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536

Orientation: TL Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
40.00	10.00	10.69	-.69
70.00	18.50	16.01	2.49
70.00	20.50	16.01	4.49
100.00	23.50	23.23	.27
125.00	30.50	30.26	.24
150.00	29.50	37.38	-7.88
165.00	39.00	41.35	-2.35
175.00	39.50	43.78	-4.28
185.00	48.50	46.01	2.49

CAPSULE W INTERMEDIATE SHELL 05

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: W Fluence: n/cm^2

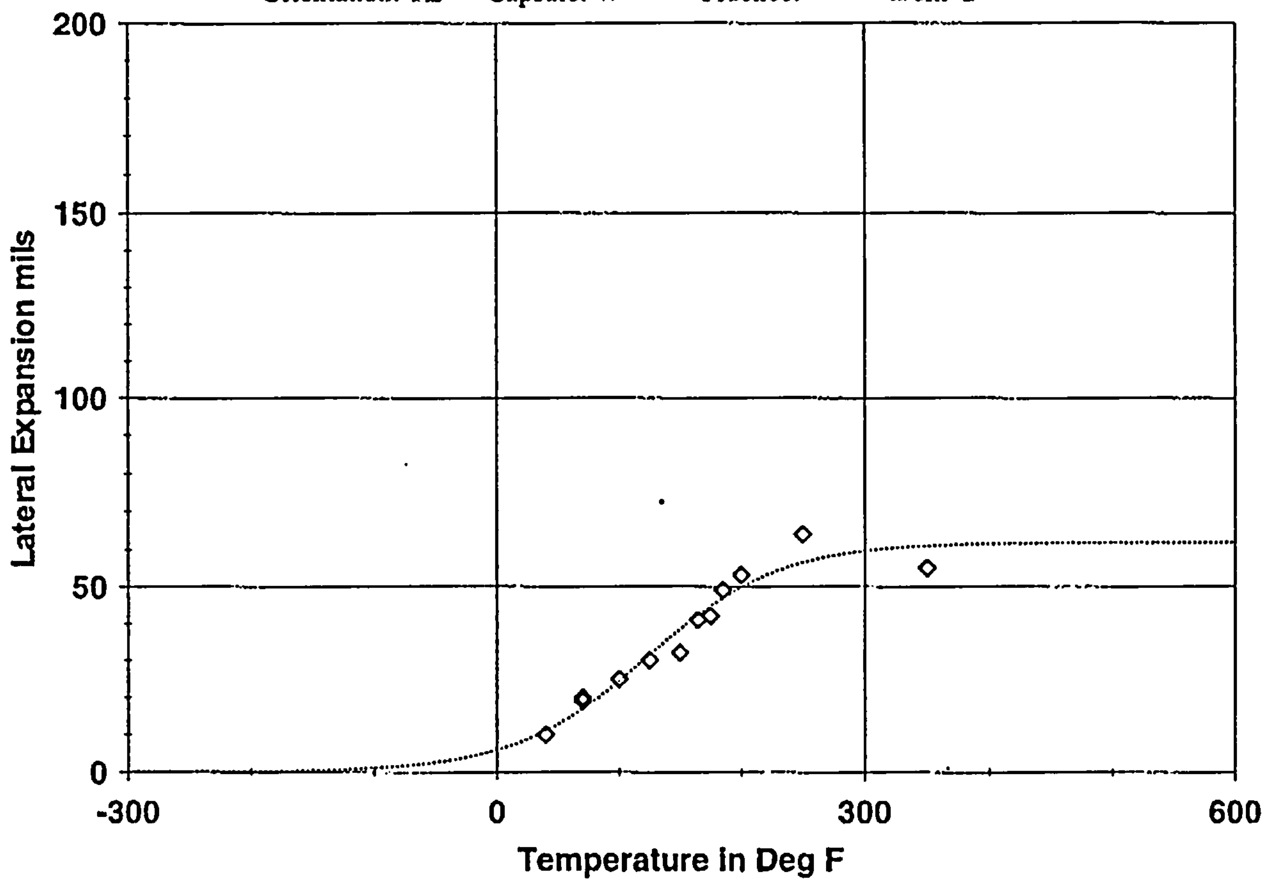
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
200.00	54.50	48.95	5.55
250.00	63.50	55.37	8.13
350.00	62.50	59.33	3.17

Correlation Coefficient = .969

CAPSULE W INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 10:43 AM
Page 1
Coefficients of Curve 3
A = 30.92 B = 30.92 C = 108.86 T0 = 123.59 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=61.8 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=138.1 Deg F
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
40.00	10.00	10.96	-.96
70.00	20.00	16.82	3.18
70.00	19.00	16.82	2.18
100.00	25.00	24.32	.68
125.00	30.00	31.32	-1.32
150.00	32.00	38.28	-6.28
165.00	41.00	42.15	-1.15
175.00	42.00	44.53	-2.53
185.00	49.00	46.72	2.28

CAPSULE W INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: W Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
200.00	53.00	49.65	3.35
250.00	64.00	56.32	7.68
350.00	55.00	60.89	-5.89

Correlation Coefficient = .971

CAPSULE X INTERMEDIATE SHELL 05 (AXIAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 10:26 AM

Page 1

Coefficients of Curve 4

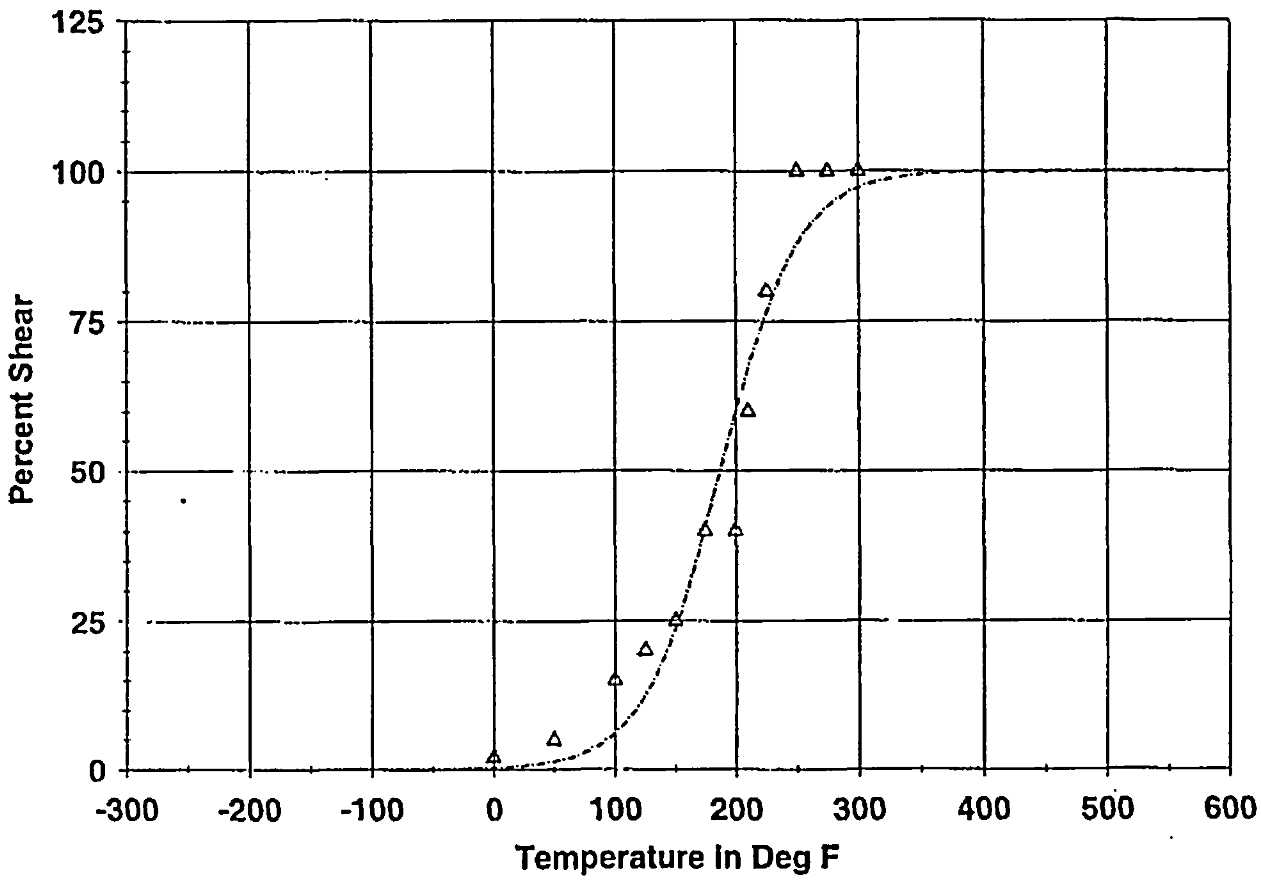
A = 50. B = 50. C = 63.84 T0 = 187.25 D = 0.00E+00

Equation is A + B * [Tanh((T-To)/(C+DT))]

Temperature at 50% Shear = 187.3

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536

Orientation: TL Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
.00	2.00	.28	1.72
50.00	5.00	1.34	3.66
100.00	15.00	6.10	8.90
125.00	20.00	12.45	7.55
125.00	20.00	12.45	7.55
150.00	25.00	23.74	1.26
175.00	40.00	40.52	-.52
200.00	40.00	59.86	-19.86
210.00	60.00	67.10	-7.10

CAPSULE X INTERMEDIATE SHELL 05 (AXIAL)

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: TL Capsule: X Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
225.00	80.00	76.54	3.46
250.00	100.00	87.72	12.28
250.00	100.00	87.72	12.28
275.00	100.00	93.99	6.01
275.00	100.00	93.99	6.01
300.00	100.00	97.16	2.84

Correlation Coefficient = .979

UNIRRADIATED SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 01:38 PM

Page 1

Coefficients of Curve 1

A = 66.6 B = 64.4 C = 66.29 T0 = 11.54 D = 0.00E+00

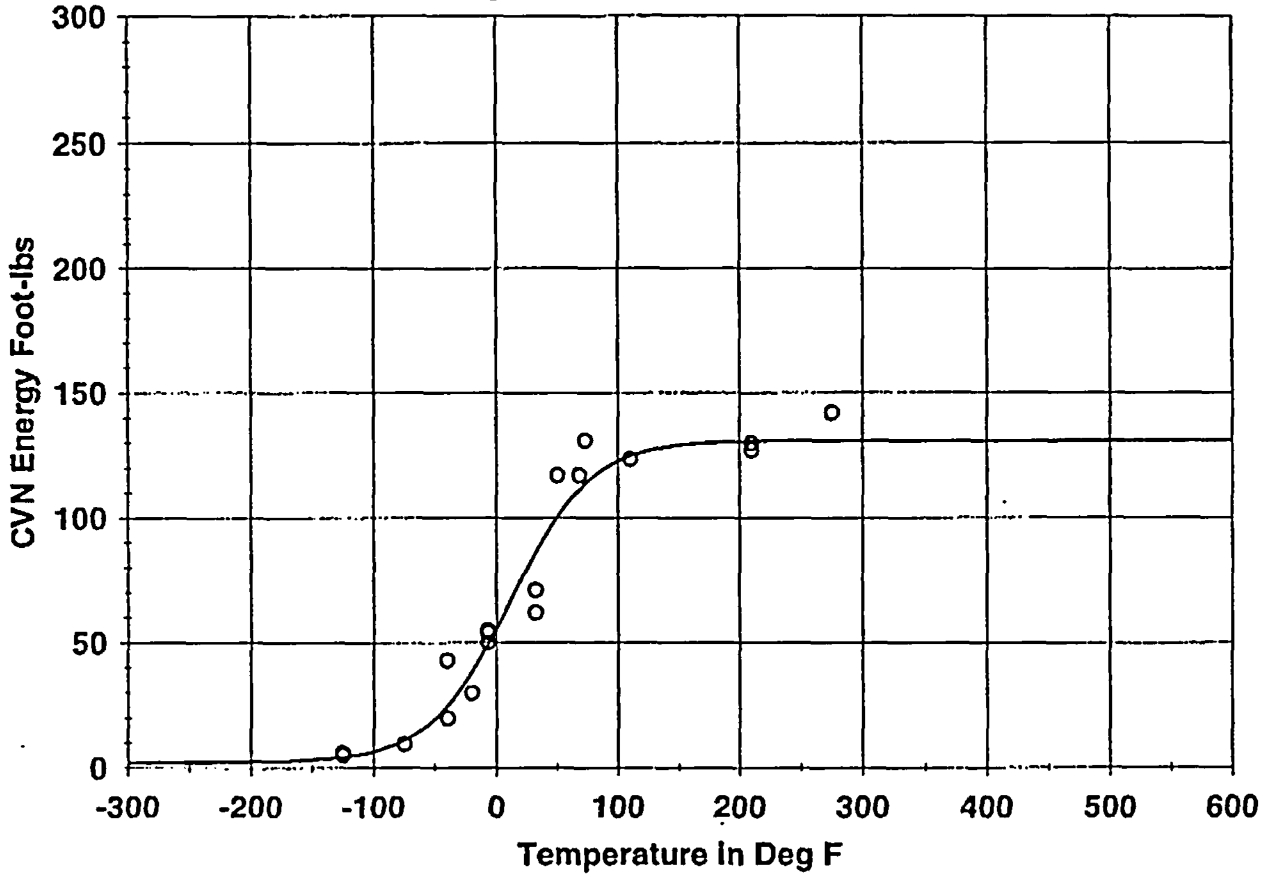
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=131.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=-31.2 Deg F Temp@50 ft-lbs=-5.9 Deg F

Plant: Watts Bar 1 Material: N/A Heat: 895075 FLUX

Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-125.00	6.00	4.26	1.74
-125.00	5.00	4.26	.74
-75.00	9.50	11.01	-1.51
-40.00	20.00	24.66	-4.66
-40.00	43.00	24.66	18.34
-20.00	30.00	38.08	-8.08
-7.00	50.00	49.04	.96
-7.00	54.00	49.04	4.96
-7.00	55.00	49.04	5.96

UNIRRADIATED SURVEILLANCE PROGRAM WELD

Plant: Watts Bar 1 Material: N/A Heat: 895075 FLUX
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

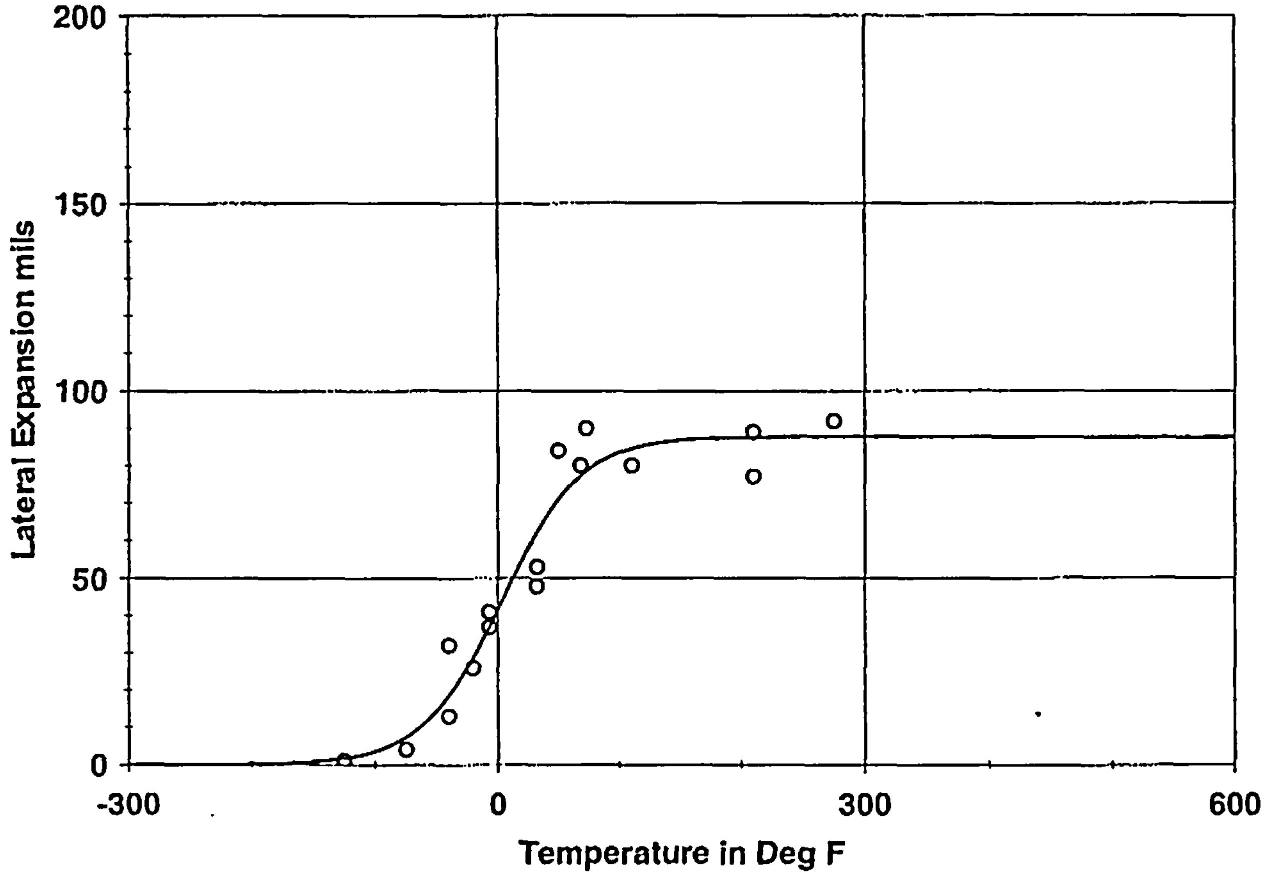
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
32.00	71.00	85.87	-14.87
32.00	62.00	85.87	-23.87
50.00	117.00	100.26	16.74
68.00	117.00	111.16	5.84
73.00	131.00	113.56	17.44
110.00	123.50	124.72	-1.22
210.00	130.00	130.68	-.68
210.00	127.00	130.68	-3.68
275.00	142.00	130.95	11.05

Correlation Coefficient = .975

UNIRRADIATED SURVIELLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 02:09 PM
Page 1
Coefficients of Curve 1
A = 43.89 B = 43.89 C = 65.14 T0 = 3.4 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=87.8 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=-9.9 Deg F
Plant: Watts Bar 1 Material: N/A Heat: 895075 FLUX
Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-125.00	1.00	1.67	-.67
-125.00	1.00	1.67	-.67
-75.00	4.00	7.25	-3.25
-40.00	13.00	18.32	-5.32
-40.00	32.00	18.32	13.68
-20.00	26.00	28.77	-2.77
-7.00	37.00	36.94	.06
-7.00	37.00	36.94	.06
-7.00	41.00	36.94	4.06

UNIRRADIATED SURVIELLANCE PROGRAM WELD

Page 2
Plant: Watts Bar 1 Material: N/A Heat: 895075 FLUX
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
32.00	53.00	62.01	-9.01
32.00	48.00	62.01	-14.01
50.00	84.00	70.84	13.16
68.00	80.00	77.16	2.84
73.00	90.00	78.52	11.48
110.00	80.00	84.58	-4.58
210.00	89.00	87.63	1.37
210.00	77.00	87.63	-10.63
275.00	92.00	87.76	4.24

Correlation Coefficient = .972

UNIRRADIATED SURVIELLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 01:53 PM

Page 1

Coefficients of Curve 1

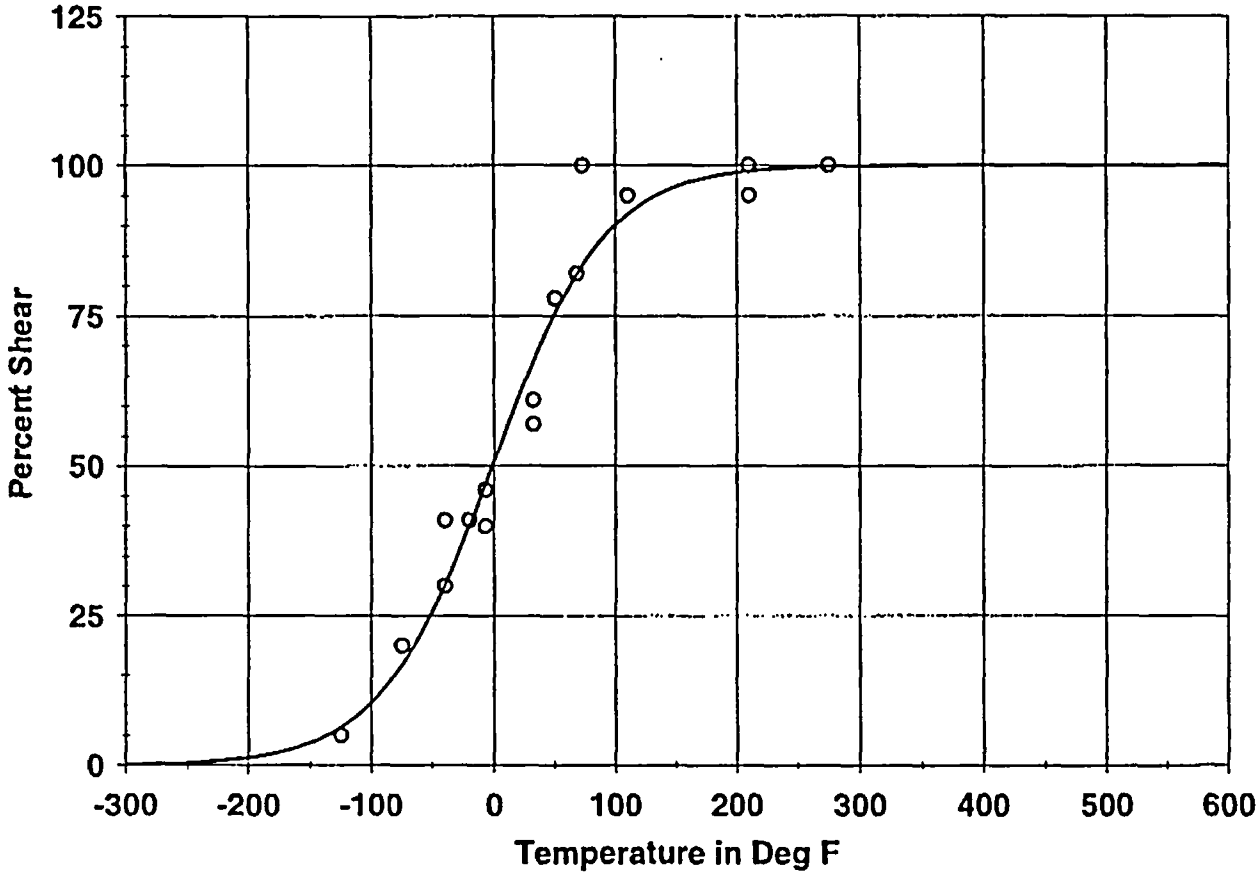
A = 50. B = 50. C = 91.87 T0 = -1.28 D = 0.00E+00

Equation is A + B * [Tanh((T-To)/(C+DT))]

Temperature at 50% Shear = -1.2

Plant: Watts Bar 1 Material: N/A Heat: 895075 FLUX

Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-125.00	5.00	6.34	-1.34
-125.00	5.00	6.34	-1.34
-75.00	20.00	16.73	3.27
-40.00	30.00	30.09	-.09
-40.00	41.00	30.09	10.91
-20.00	41.00	39.95	1.05
-7.00	46.00	46.89	-.89
-7.00	40.00	46.89	-6.89
-7.00	46.00	46.89	-.89

UNIRRADIATED SURVIELLANCE PROGRAM WELD

Page 2
Plant: Watts Bar 1 Material: N/A Heat: 895075 FLUX
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
32.00	61.00	67.36	-6.36
32.00	57.00	67.36	-10.36
50.00	78.00	75.33	2.67
68.00	82.00	81.88	.12
73.00	100.00	83.44	16.56
110.00	95.00	91.85	3.15
210.00	100.00	99.00	1.00
210.00	95.00	99.00	-4.00
275.00	100.00	99.76	.24

Correlation Coefficient = .982

CAPSULE U SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 01:38 PM

Page 1

Coefficients of Curve 2

A = 72.6 B = 70.4 C = 119.21 T0 = 45.94 D = 0.00E+00

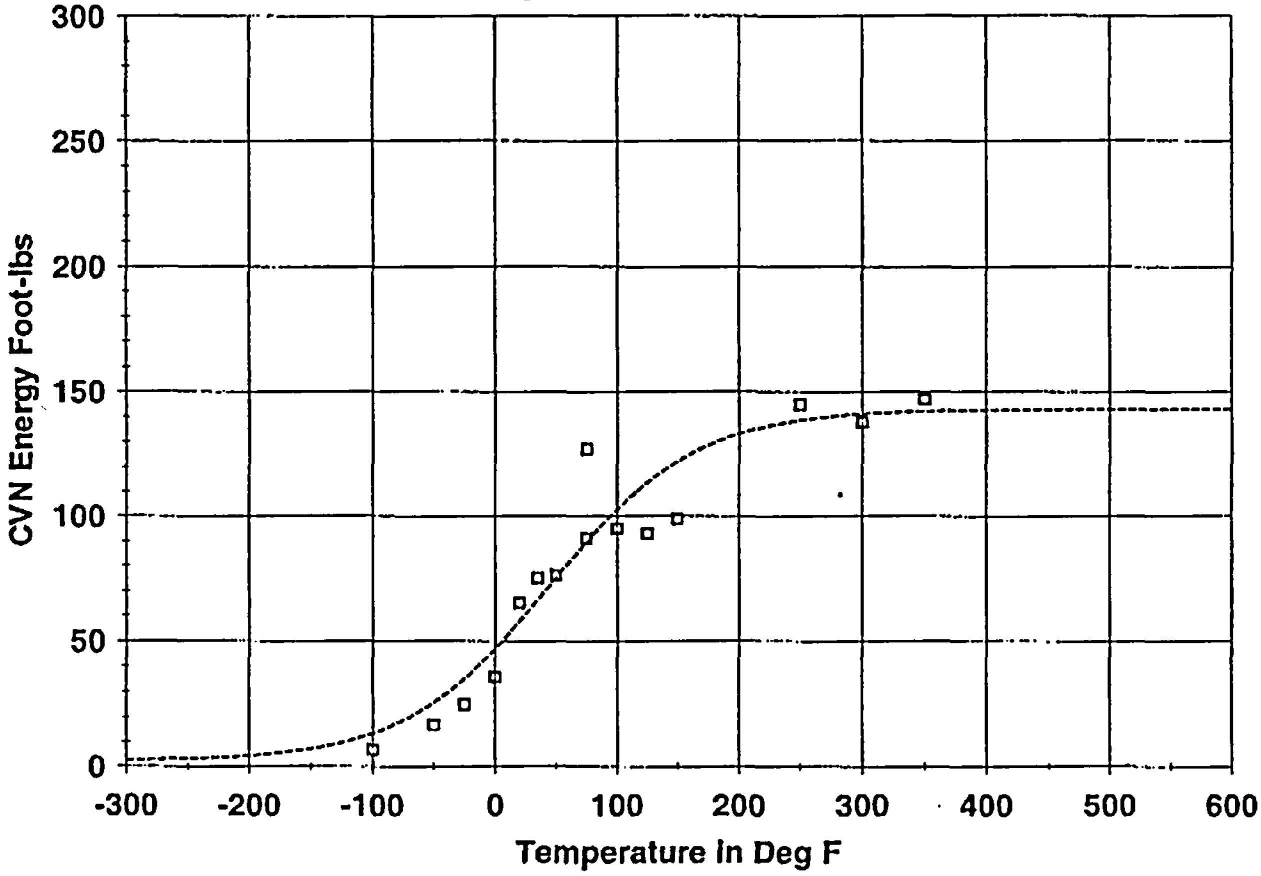
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=143.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=-37.6 Deg F Temp@50 ft-lbs=6.3 Deg F

Plant: Watts Bar 1 Material: N/A Heat: 895075

Orientation: NA Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-100.00	7.00	13.40	-6.40
-50.00	17.00	25.66	-8.66
-25.00	25.00	35.04	-10.04
.00	36.00	46.74	-10.74
20.00	65.00	57.52	7.48
35.00	75.00	66.16	8.84
50.00	76.00	75.00	1.00
75.00	127.00	89.43	37.57
75.00	91.00	89.43	1.57

CAPSULE U SURVEILLANCE PROGRAM WELD

Plant: Watts Bar 1 Material: N/A Heat: 895075
Orientation: NA Capsule: U Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
100.00	95.00	102.50	-7.50
125.00	93.00	113.47	-20.47
150.00	99.00	122.08	-23.08
250.00	145.00	138.56	6.44
300.00	138.00	141.04	-3.04
350.00	147.00	142.15	4.85

Correlation Coefficient = .949

CAPSULE U SURVIELLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 02:10 PM

Page 1

Coefficients of Curve 2

A = 38.43 B = 38.43 C = 65.63 T0 = 13.24 D = 0.00E+00

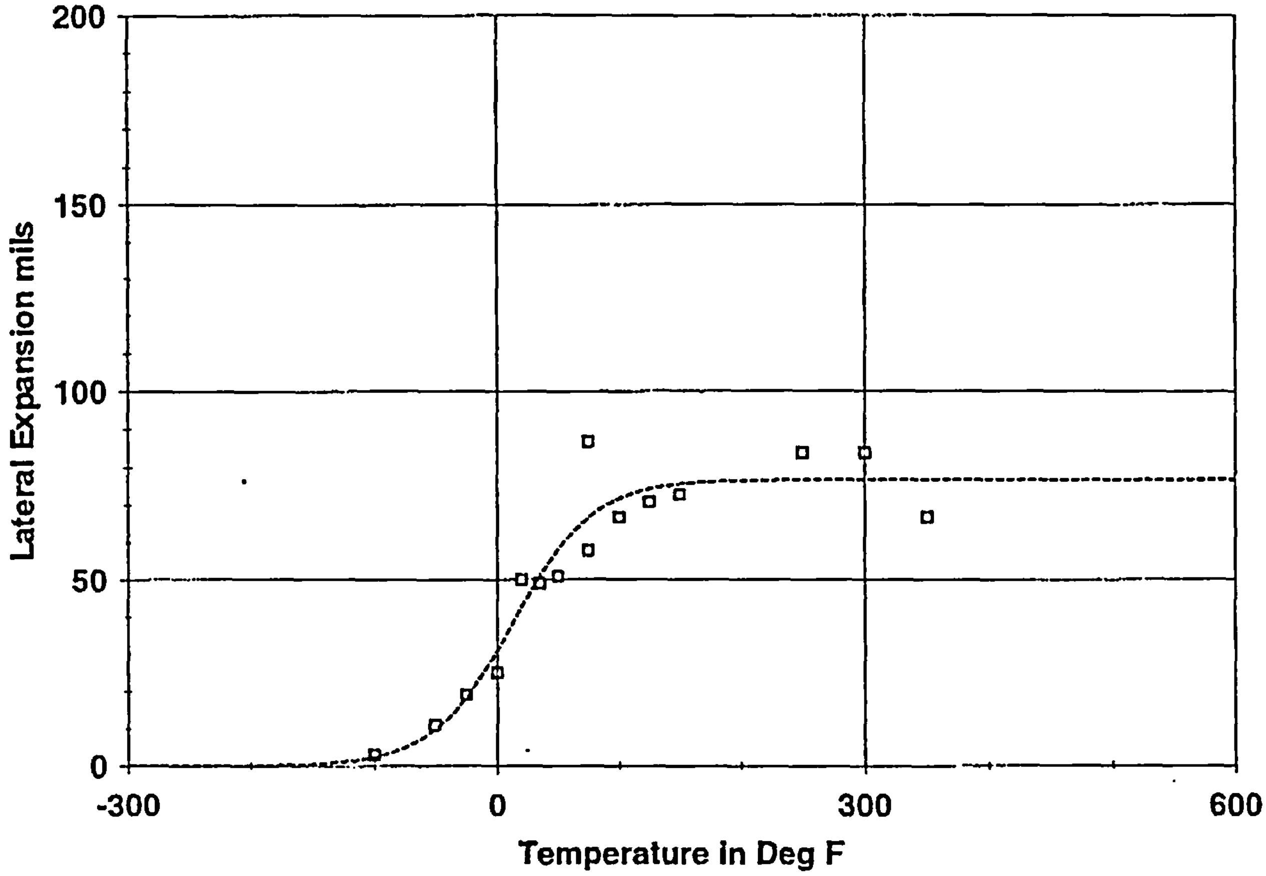
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=76.9 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=7.4 Deg F

Plant: Watts Bar 1 Material: N/A Heat: 895075

Orientation: NA Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-100.00	3.00	2.36	.64
-50.00	11.00	9.77	1.23
-25.00	19.00	18.27	.73
.00	25.00	30.78	-5.78
20.00	50.00	42.38	7.62
35.00	49.00	50.73	-1.73
50.00	51.00	57.96	-6.96
75.00	87.00	66.71	20.29
75.00	58.00	66.71	-8.71

CAPSULE U SURVIELLANCE PROGRAM WELD

Page 2
Plant: Watts Bar 1 Material: N/A Heat: 895075
Orientation: NA Capsule: U Fluence: n/cm^2

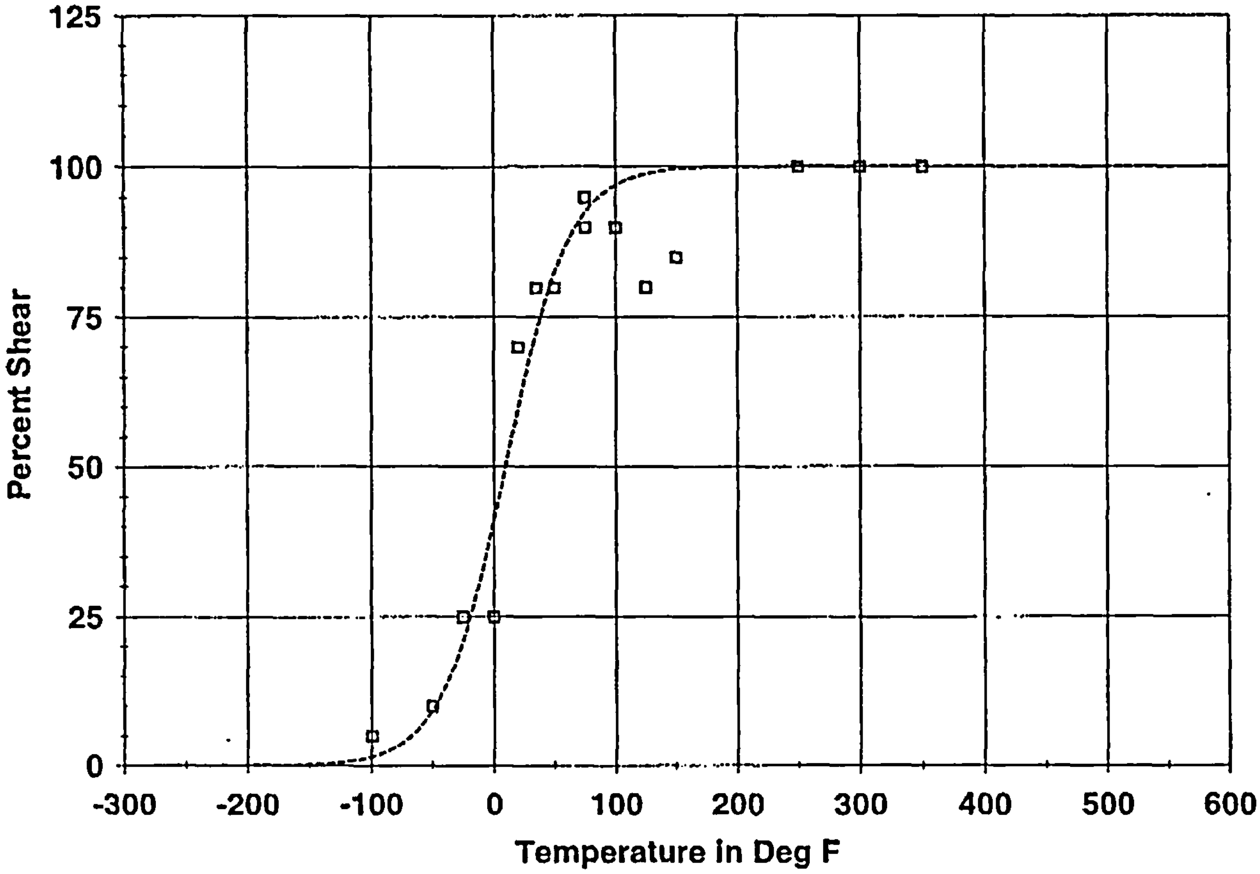
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
100.00	67.00	71.76	-4.76
125.00	71.00	74.39	-3.39
150.00	73.00	75.69	-2.69
250.00	84.00	76.81	7.19
300.00	84.00	76.85	7.15
350.00	67.00	76.86	-9.86

Correlation Coefficient = .957

CAPSULE U SURVIELLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 01:53 PM
Page 1
Coefficients of Curve 2
A = 50. B = 50. C = 52.19 T0 = 9.58 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 9.6
Plant: Watts Bar 1 Material: N/A Heat: 895075
Orientation: NA Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100.00	5.00	1.48	3.52
-50.00	10.00	9.25	.75
-25.00	25.00	20.99	4.01
.00	25.00	40.92	-15.92
20.00	70.00	59.85	10.15
35.00	80.00	72.59	7.41
50.00	80.00	82.47	-2.47
75.00	95.00	92.46	2.54
75.00	90.00	92.46	-2.46

CAPSULE U SURVIELLANCE PROGRAM WELD

Page 2
Plant: Watts Bar 1 Material: N/A Heat: 895075
Orientation: NA Capsule: U Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
100.00	90.00	96.97	-6.97
125.00	80.00	98.81	-18.81
150.00	85.00	99.54	-14.54
250.00	100.00	99.99	.01
300.00	100.00	100.00	.00
350.00	100.00	100.00	.00

Correlation Coefficient = .972

CAPSULE W SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 01:39 PM

Page 1

Coefficients of Curve 3

A = 57.1 B = 54.9 C = 97.49 T0 = 52.01 D = 0.00E+00

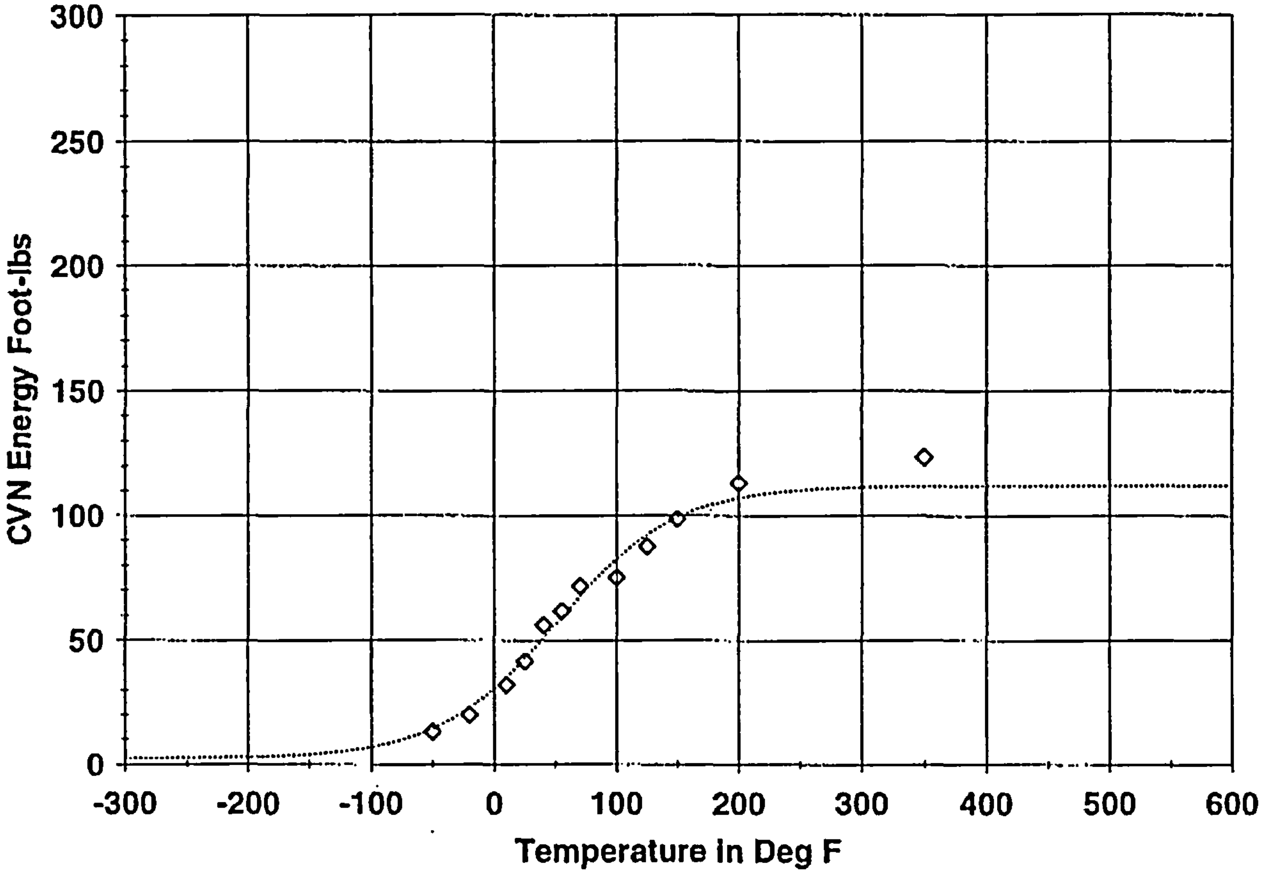
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=112.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=-.7 Deg F Temp@50 ft-lbs=39.4 Deg F

Plant: Watts Bar 1 Material: N/A Heat: 895075

Orientation: NA Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-50.00	13.00	14.26	-1.26
-20.00	20.00	22.61	-2.61
10.00	32.00	34.81	-2.81
25.00	41.50	42.27	-.77
40.00	56.00	50.37	5.63
55.00	61.50	58.79	2.71
70.00	71.50	67.12	4.38
100.00	75.00	82.14	-7.14
125.00	87.50	91.93	-4.43

CAPSULE W SURVEILLANCE PROGRAM WELD

Page 2
Plant: Watts Bar 1 Material: N/A Heat: 895075
Orientation: NA Capsule: W Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
150.00	98.50	99.03	-.53
200.00	113.00	106.97	6.03
350.00	123.50	111.76	11.74

Correlation Coefficient = .990

CAPSULE W SURVIELLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 02:10 PM

Page 1

Coefficients of Curve 3

A = 44.58 B = 44.58 C = 95.29 T0 = 42.68 D = 0.00E+00

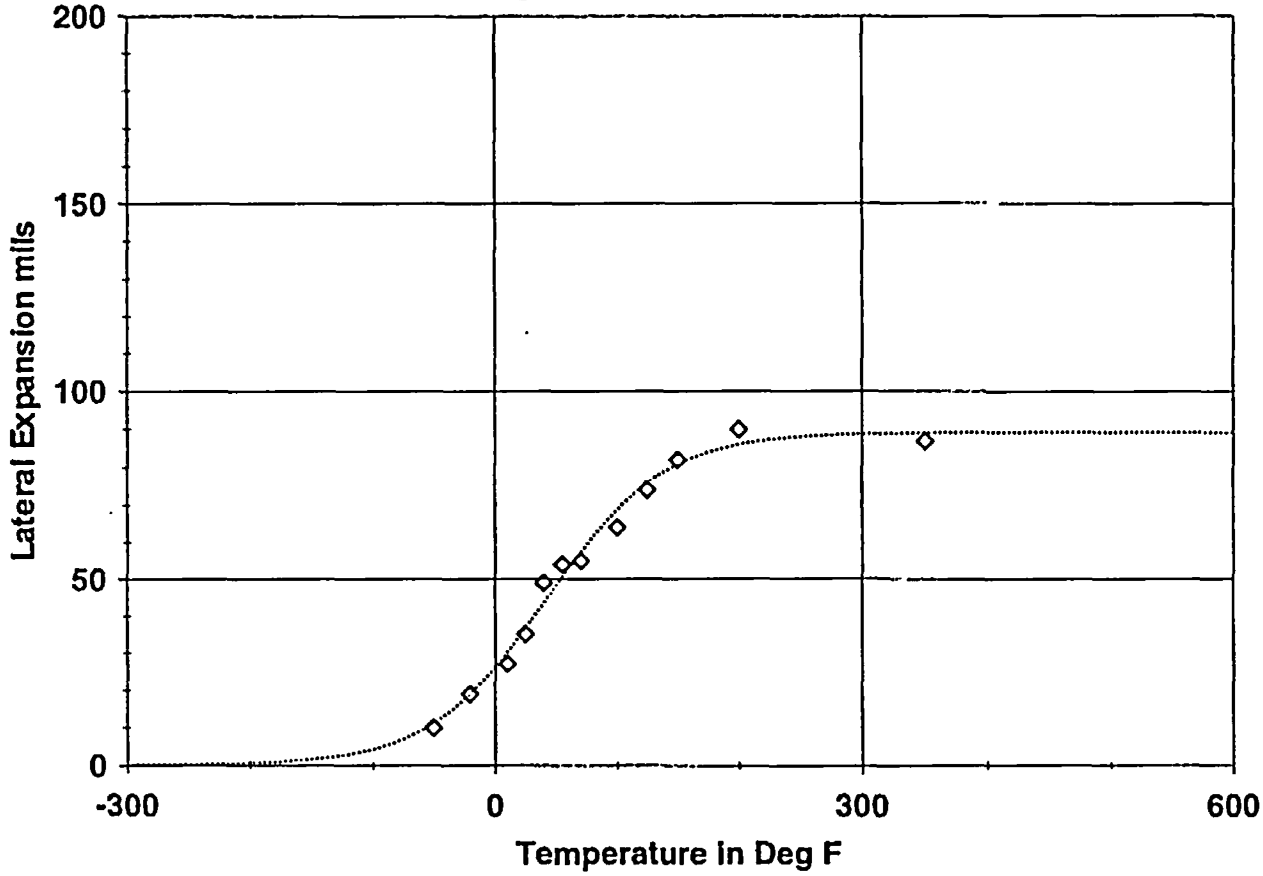
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=89.2 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=21.9 Deg F

Plant: Watts Bar 1 Material: N/A Heat: 895075

Orientation: NA Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-50.00	10.00	11.15	-1.15
-20.00	19.00	18.86	.14
10.00	27.00	29.86	-2.86
25.00	35.00	36.40	-1.40
40.00	49.00	43.32	5.68
55.00	54.00	50.31	3.69
70.00	55.00	57.02	-2.02
100.00	64.00	68.57	-4.57
125.00	74.00	75.70	-1.70

CAPSULE W SURVIELLANCE PROGRAM WELD

Page 2
Plant: Watts Bar 1 Material: N/A Heat: 895075
Orientation: NA Capsule: W Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
150.00	82.00	80.67	1.33
200.00	90.00	85.99	4.01
350.00	87.00	89.01	-2.01

Correlation Coefficient = .993

CAPSULE W SURVIELLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 01:53 PM

Page 1

Coefficients of Curve 3

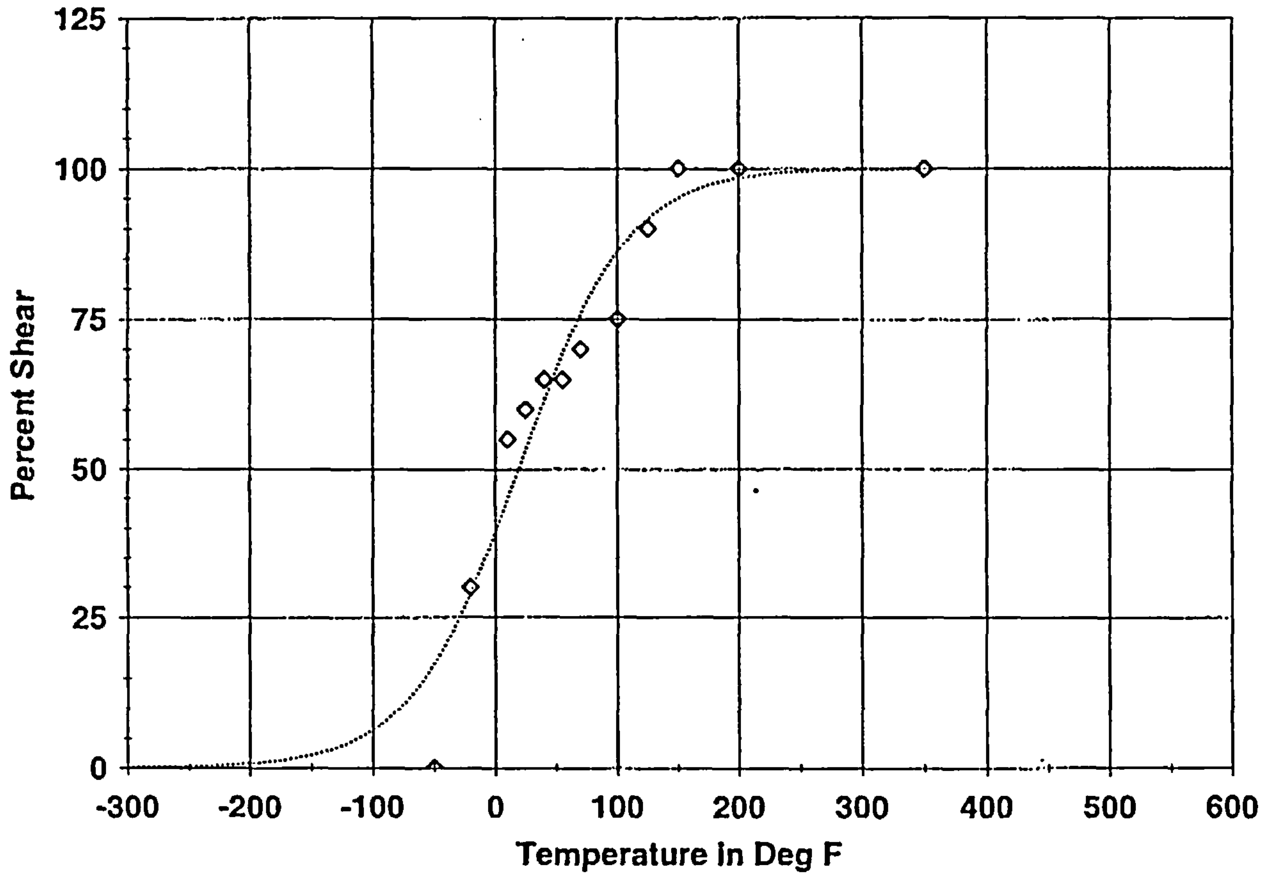
A = 50. B = 50. C = 88.62 T0 = 19.8 D = 0.00E+00

Equation is A + B * [Tanh((T-To)/(C+DT))]

Temperature at 50% Shear = 19.9

Plant: Watts Bar 1 Material: N/A Heat: 895075

Orientation: NA Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50.00	.00	17.15	-17.15
-20.00	30.00	28.94	1.06
10.00	55.00	44.49	10.51
25.00	60.00	52.93	7.07
40.00	65.00	61.20	3.80
55.00	65.00	68.88	-3.88
70.00	70.00	75.64	-5.64
100.00	75.00	85.94	-10.94
125.00	90.00	91.48	-1.48

CAPSULE W SURVIELLANCE PROGRAM WELD

Page 2
Plant: Watts Bar 1 Material: N/A Heat: 895075
Orientation: NA Capsule: W Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
150.00	100.00	94.97	5.03
200.00	100.00	98.32	1.68
350.00	100.00	99.94	.06

Correlation Coefficient = .967

CAPSULE X SURVEILLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 01:39 PM

Page 1

Coefficients of Curve 4

A = 68.1 B = 65.9 C = 114.7 T0 = 70.21 D = 0.00E+00

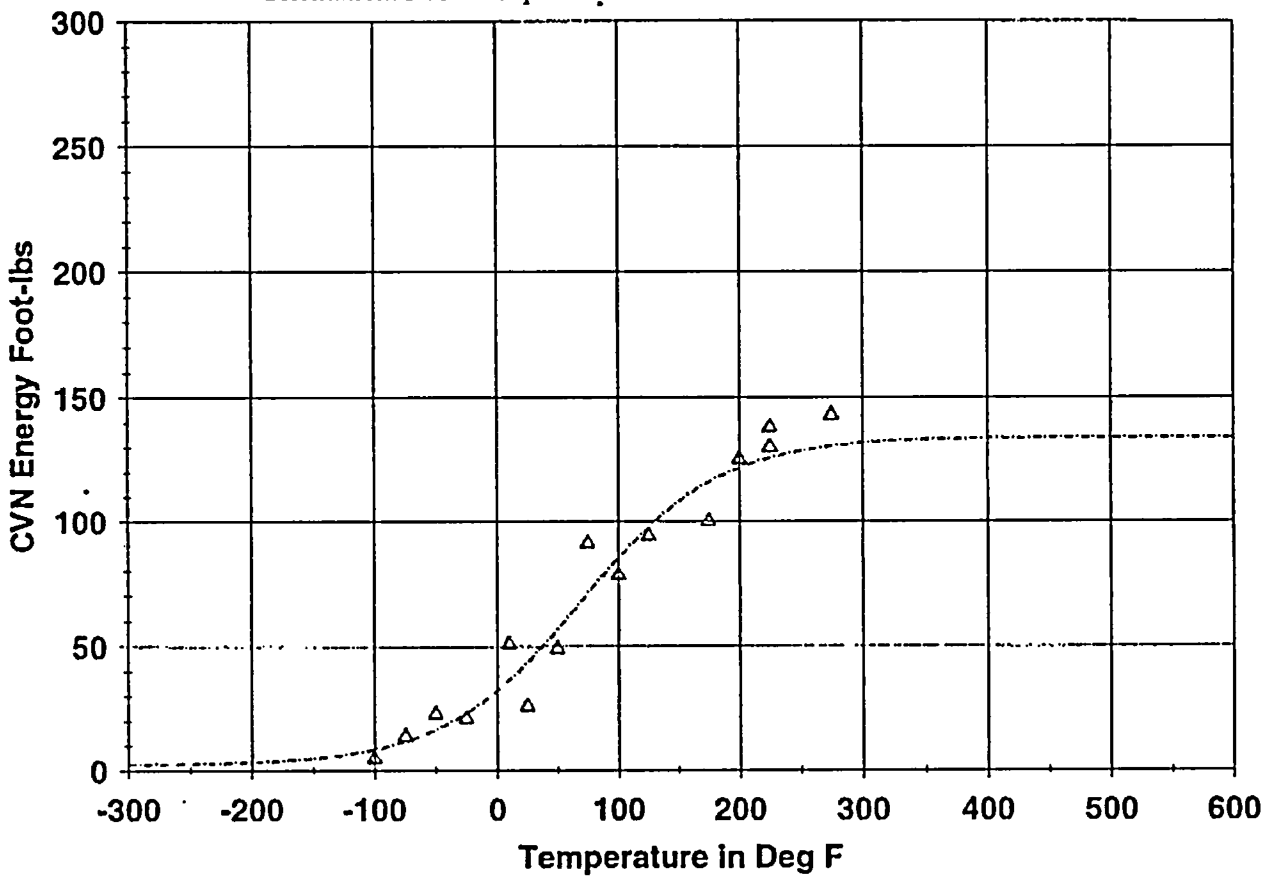
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=134.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=-5.4 Deg F Temp@50 ft-lbs=37.9 Deg F

Plant: Watts Bar 1 Material: N/A Heat: 895075

Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-100.00	5.00	8.64	-3.64
-75.00	14.00	11.91	2.09
-50.00	23.00	16.63	6.37
-25.00	21.00	23.25	-2.25
10.00	51.00	36.37	14.63
25.00	26.00	43.39	-17.39
50.00	49.00	56.61	-7.61
75.00	91.00	70.85	20.15
100.00	78.00	84.84	-6.84

CAPSULE X SURVEILLANCE PROGRAM WELD

Page 2
Plant: Watts Bar 1 Material: N/A Heat: 895075
Orientation: NA Capsule: X Fluence: n/cm^2

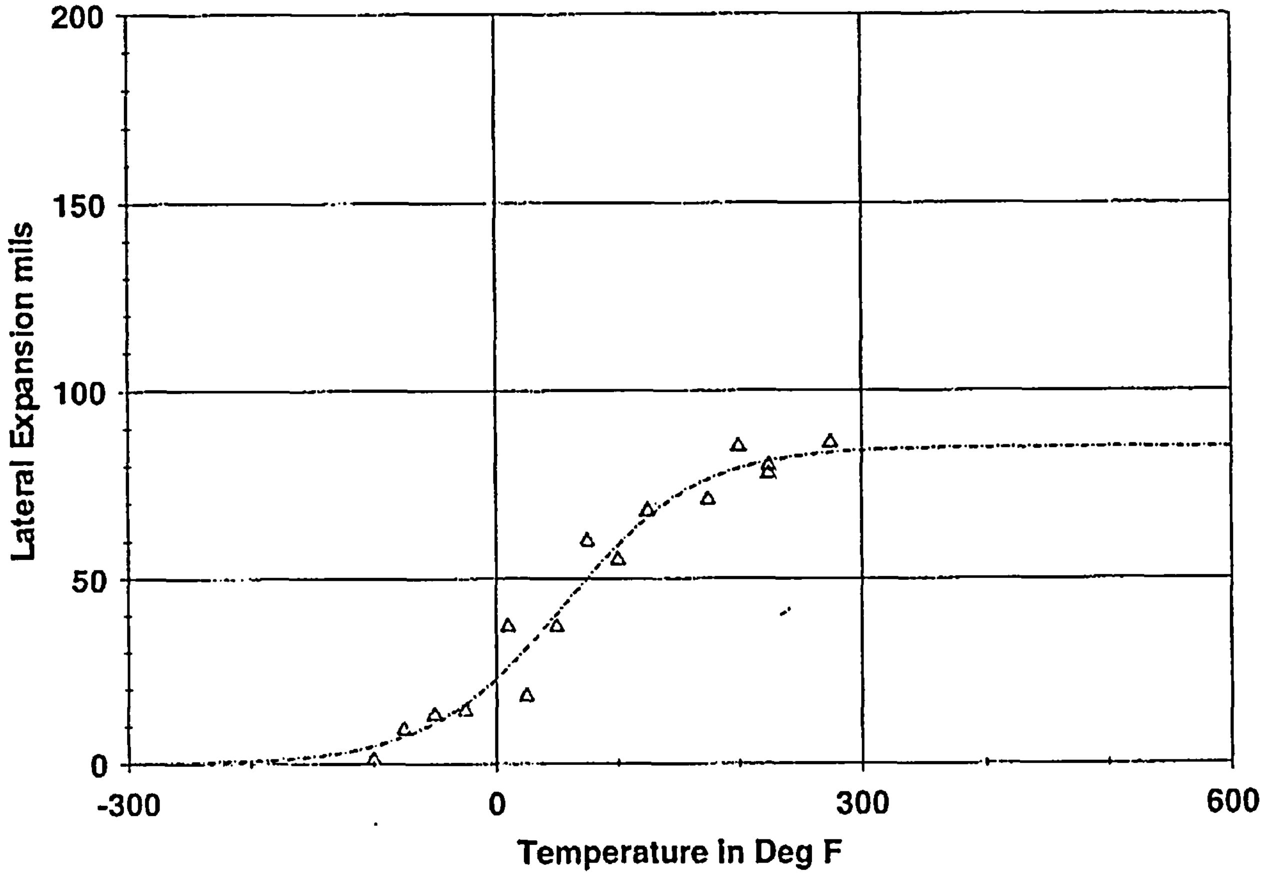
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
125.00	94.00	97.39	-3.39
175.00	100.00	115.74	-15.74
200.00	125.00	121.58	3.42
225.00	138.00	125.69	12.31
225.00	130.00	125.69	4.31
275.00	143.00	130.39	12.61

Correlation Coefficient = .975

CAPSULE X SURVIELLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 02:10 PM
Page 1
Coefficients of Curve 4
A = 42.49 B = 42.49 C = 109.65 T0 = 55.42 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=85.0 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=35.9 Deg F
Plant: Watts Bar 1 Material: N/A Heat: 895075
Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-100.00	1.00	4.71	-3.71
-75.00	9.00	7.21	1.79
-50.00	13.00	10.84	2.16
-25.00	14.00	15.93	-1.93
10.00	37.00	25.83	11.17
25.00	18.00	31.00	-13.00
50.00	37.00	40.39	-3.39
75.00	60.00	50.00	10.00
100.00	55.00	58.87	-3.87

CAPSULE X SURVIELLANCE PROGRAM WELD

Page 2
Plant: Watts Bar 1 Material: N/A Heat: 895075
Orientation: NA Capsule: X Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
125.00	68.00	66.34	1.66
175.00	71.00	76.36	-5.36
200.00	85.00	79.31	5.69
225.00	78.00	81.29	-3.29
225.00	80.00	81.29	-1.29
275.00	86.00	83.46	2.54

Correlation Coefficient = .980

CAPSULE X SURVIELLANCE PROGRAM WELD

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 01:53 PM

Page 1

Coefficients of Curve 4

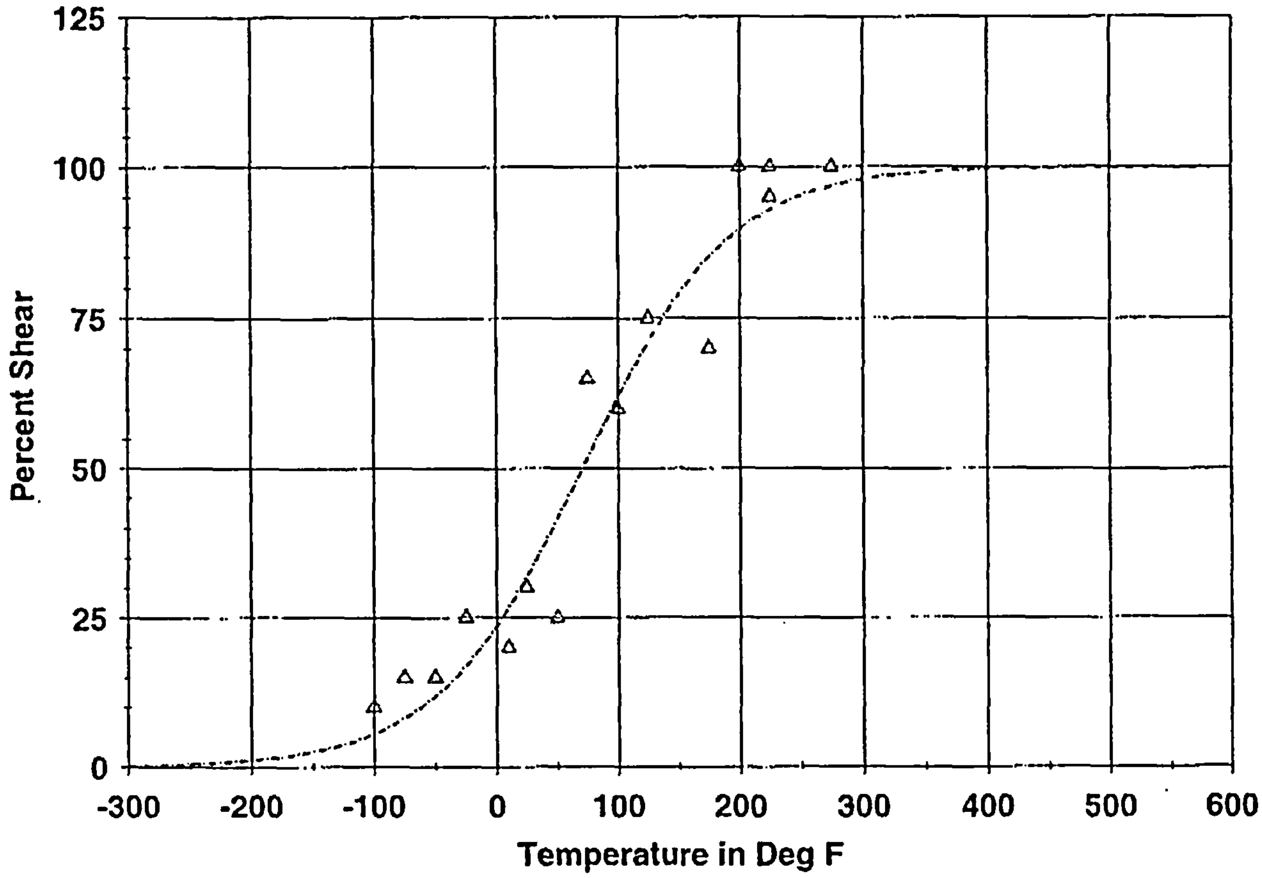
A = 50. B = 50. C = 120.09 T0 = 70.86 D = 0.00E+00

Equation is A + B * [Tanh((T-To)/(C+DT))]

Temperature at 50% Shear = 70.9

Plant: Watts Bar 1 Material: N/A · Heat: 895075

Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100.00	10.00	5.49	4.51
-75.00	15.00	8.10	6.90
-50.00	15.00	11.79	3.21
-25.00	25.00	16.85	8.15
10.00	20.00	26.63	-6.63
25.00	30.00	31.78	-1.78
50.00	25.00	41.40	-16.40
75.00	65.00	51.72	13.28
100.00	60.00	61.90	-1.90

CAPSULE X SURVIELLANCE PROGRAM WELD

Page 2
Plant: Watts Bar 1 Material: N/A Heat: 895075
Orientation: NA Capsule: X Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
125.00	75.00	71.13	3.87
175.00	70.00	85.00	-15.00
200.00	100.00	89.57	10.43
225.00	95.00	92.87	2.13
225.00	100.00	92.87	7.13
275.00	100.00	96.77	3.23

Correlation Coefficient = .970

UNIRRADIATED HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 03:18 PM

Coefficients of Curve 1

A = 45.6 B = 43.4 C = 99.65 T0 = -18.8 D = 0.00E+00

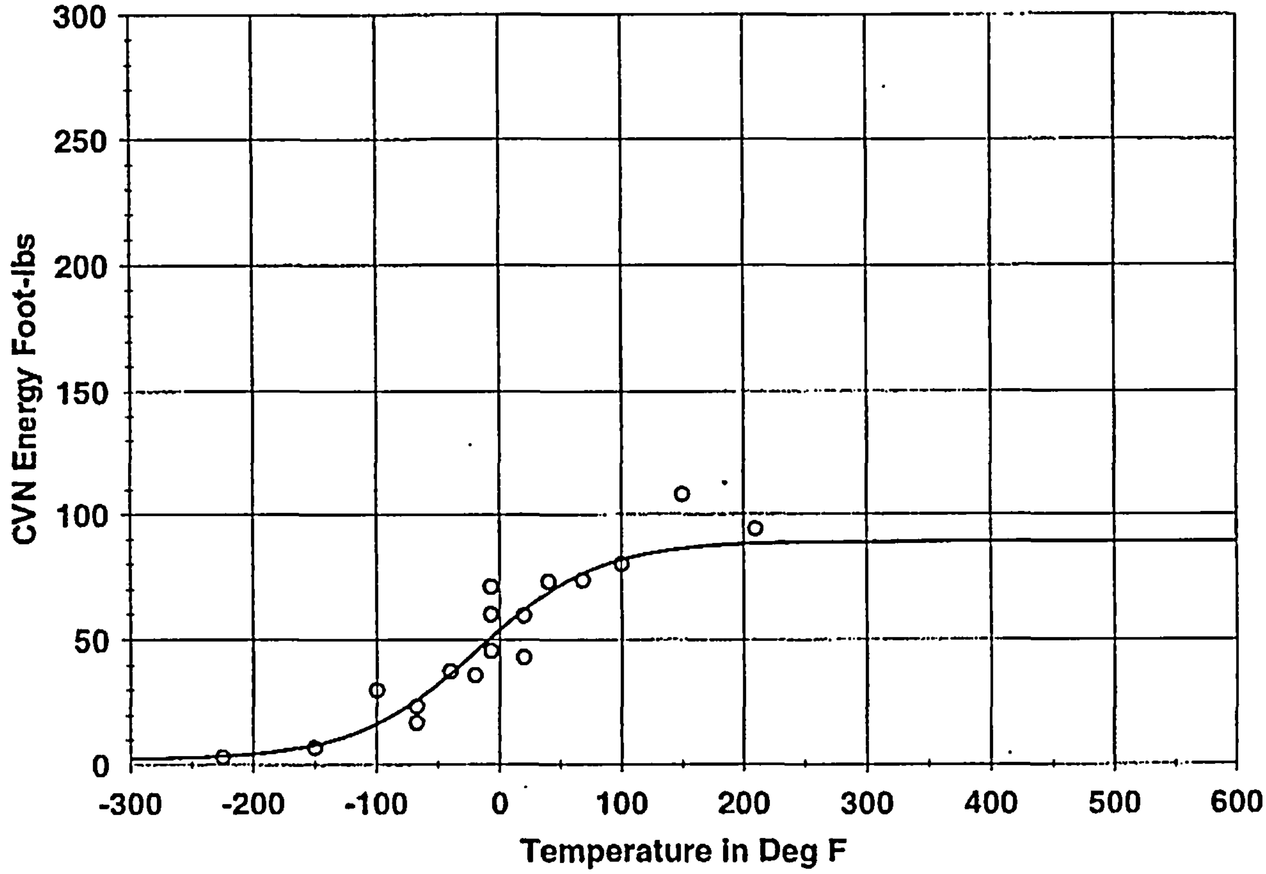
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=89.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=-56.2 Deg F Temp@50 ft-lbs=-8.6 Deg F

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536

Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-225.00	3.00	3.56	-.56
-225.00	3.00	3.56	-.56
-150.00	7.00	8.02	-1.02
-100.00	30.00	16.42	13.58
-67.00	17.00	26.10	-9.10
-67.00	23.50	26.10	-2.60
-40.00	37.50	36.50	1.00
-20.00	36.00	45.08	-9.08
-7.00	71.00	50.71	20.29

UNIRRADIATED HEAT AFFECTED ZONE

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-7.00	45.50	50.71	-5.21
-7.00	60.00	50.71	9.29
20.00	43.00	61.69	-18.69
20.00	59.50	61.69	-2.19
40.00	73.00	68.60	4.40
68.00	73.50	76.06	-2.56
100.00	80.00	81.68	-1.68
150.00	108.00	86.16	21.84
210.00	94.00	88.13	5.87

Correlation Coefficient = .948

UNIRRADIATED HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 03:40 PM

Page 1

Coefficients of Curve 1

A = 33.16 B = 33.16 C = 114.43 T0 = -7. D = 0.00E+00

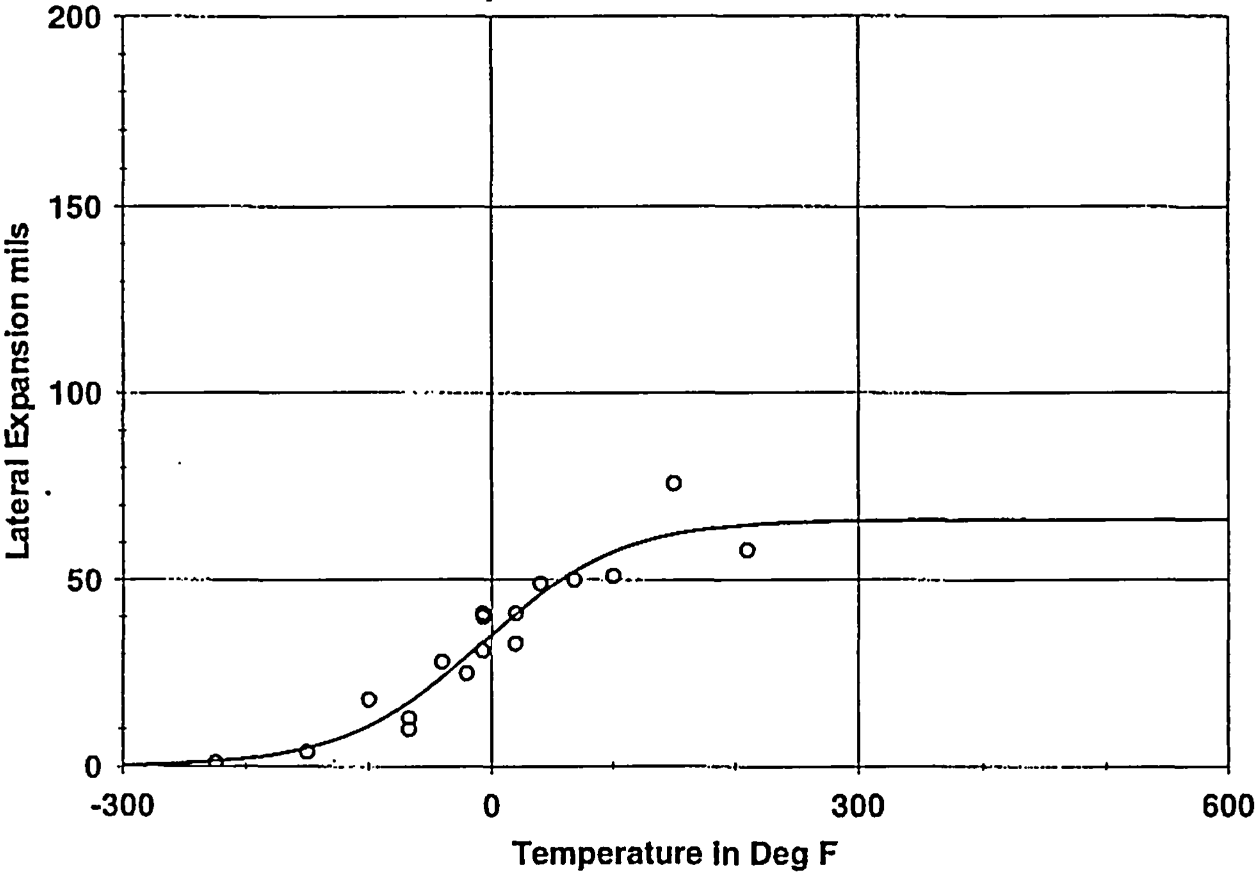
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=66.3 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=-.6 Deg F

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536

Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-225.00	1.00	1.44	-.44
-225.00	1.00	1.44	-.44
-150.00	4.00	5.03	-1.03
-100.00	18.00	10.91	7.09
-67.00	10.00	17.21	-7.21
-67.00	13.00	17.21	-4.21
-40.00	28.00	23.85	4.15
-20.00	25.00	29.41	-4.41
-7.00	41.00	33.16	7.84

UNIRRADIATED HEAT AFFECTED ZONE

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

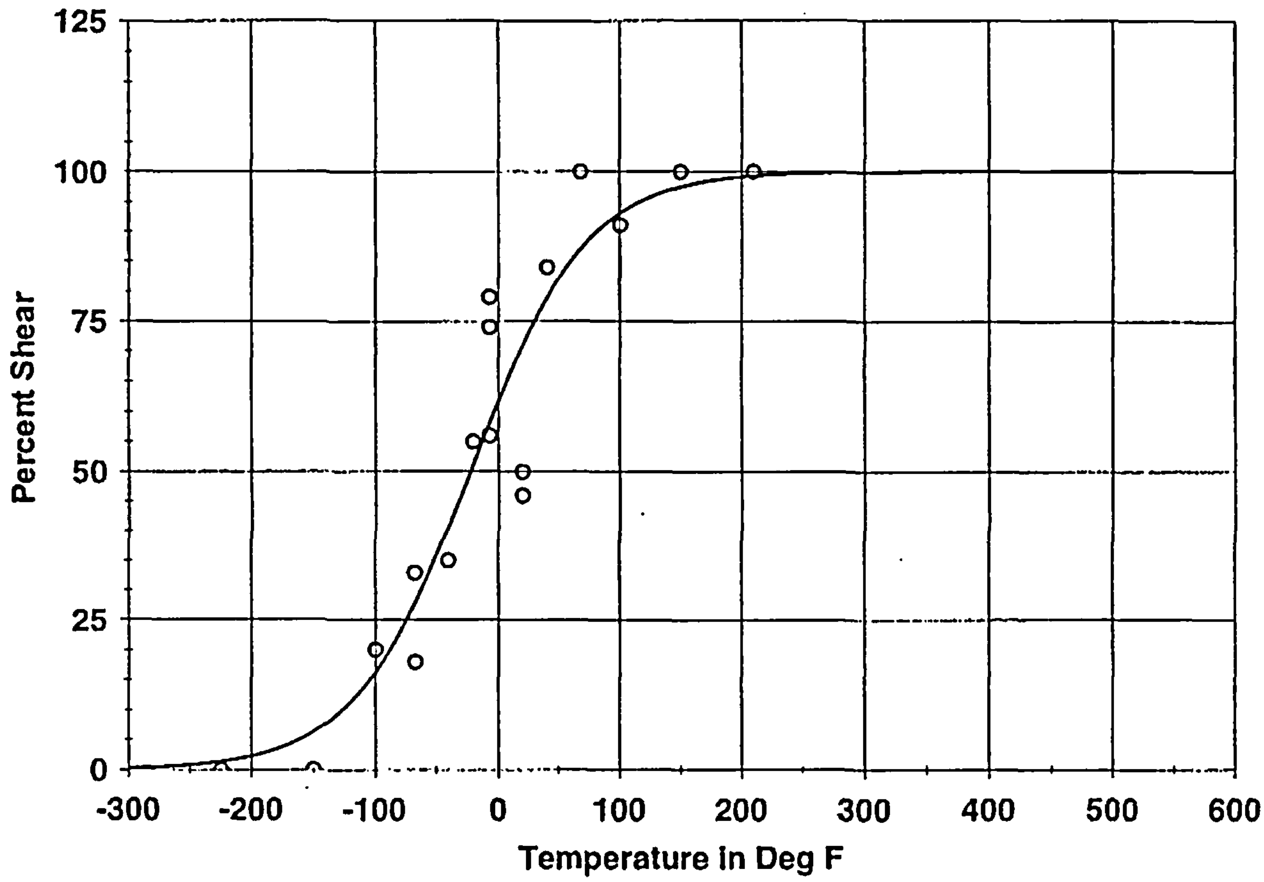
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-7.00	31.00	33.16	-2.16
-7.00	40.00	33.16	6.84
20.00	33.00	40.84	-7.84
20.00	41.00	40.84	.16
40.00	49.00	46.06	2.94
68.00	50.00	52.24	-2.24
100.00	51.00	57.46	-6.46
150.00	76.00	62.31	13.69
210.00	58.00	64.86	-6.86

Correlation Coefficient = .958

UNIRRADIATED HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 03:33 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 94.74 T0 = -22.26 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = -22.2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-225.00	.00	1.37	-1.37
-225.00	.00	1.37	-1.37
-150.00	.00	6.32	-6.32
-100.00	20.00	16.23	3.77
-67.00	18.00	28.00	-10.00
-67.00	33.00	28.00	5.00
-40.00	35.00	40.75	-5.75
-20.00	55.00	51.19	3.81
-7.00	79.00	57.99	21.01

UNIRRADIATED HEAT AFFECTED ZONE

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-7.00	56.00	57.99	-1.99
-7.00	74.00	57.99	16.01
20.00	50.00	70.93	-20.93
20.00	46.00	70.93	-24.93
40.00	84.00	78.82	5.18
68.00	100.00	87.05	12.95
100.00	91.00	92.96	-1.96
150.00	100.00	97.43	2.57
210.00	100.00	99.26	.74

Correlation Coefficient = .948

CAPSULE U HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 03:18 PM

Page 1

Coefficients of Curve 2

A = 40.6 B = 38.4 C = 91.79 T0 = 20.68 D = 0.00E+00

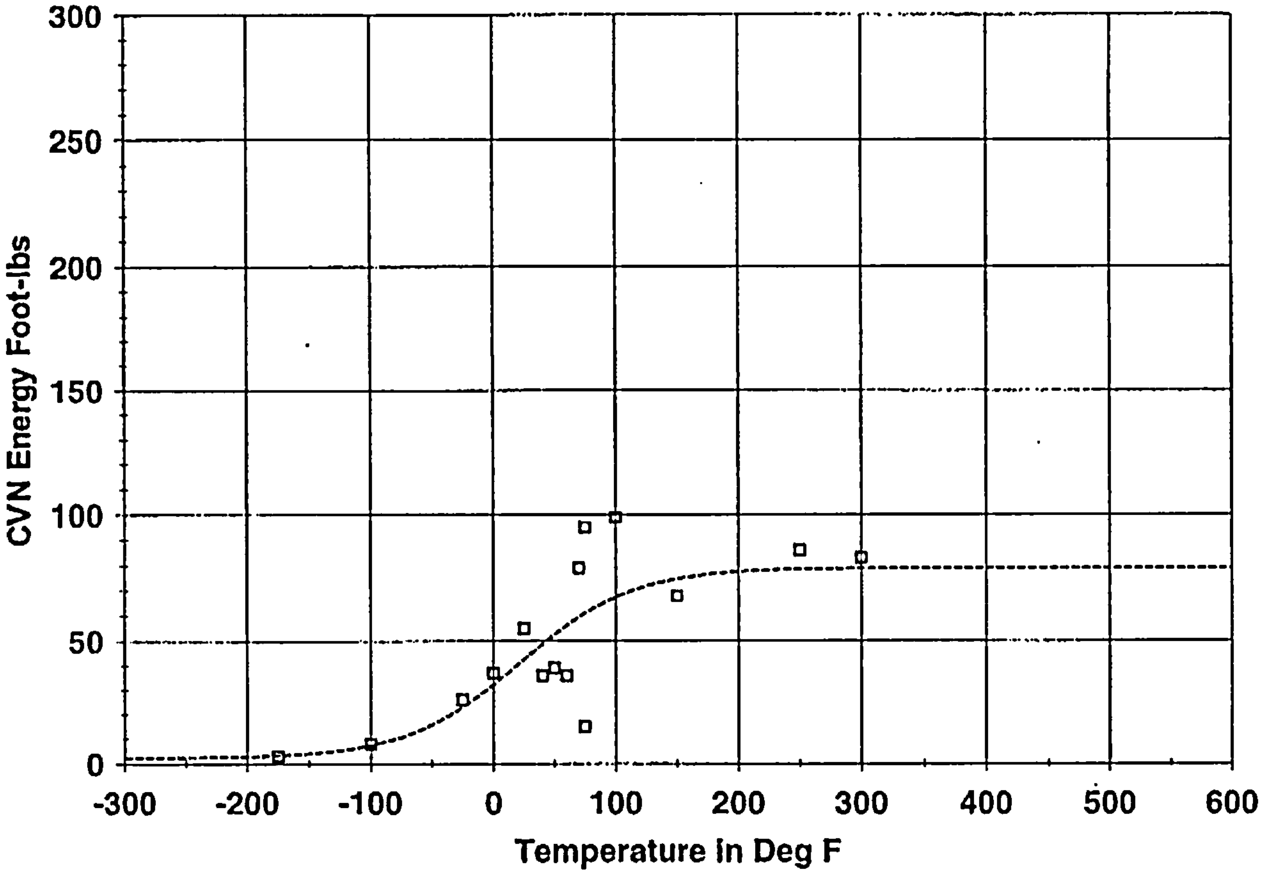
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=79.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=-5.3 Deg F Temp@50 ft-lbs=43.7 Deg F

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536

Orientation: NA Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-175.00	3.00	3.27	-.27
-100.00	8.00	7.37	.63
-25.00	26.00	22.93	3.07
.00	37.00	32.09	4.91
25.00	55.00	42.41	12.59
40.00	36.00	48.56	-12.56
50.00	39.00	52.46	-13.46
60.00	36.00	56.11	-20.11
70.00	79.00	59.45	19.55

CAPSULE U HEAT AFFECTED ZONE

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: U Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
75.00	95.00	61.00	34.00
75.00	15.00	61.00	-46.00
100.00	99.00	67.42	31.58
150.00	68.00	74.67	-6.67
250.00	86.00	78.48	7.52
300.00	83.00	78.83	4.17

Correlation Coefficient = .780

CAPSULE U HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 03:40 PM

Page 1

Coefficients of Curve 2

A = 27.21 B = 27.21 C = 80.96 T0 = 27.31 D = 0.00E+00

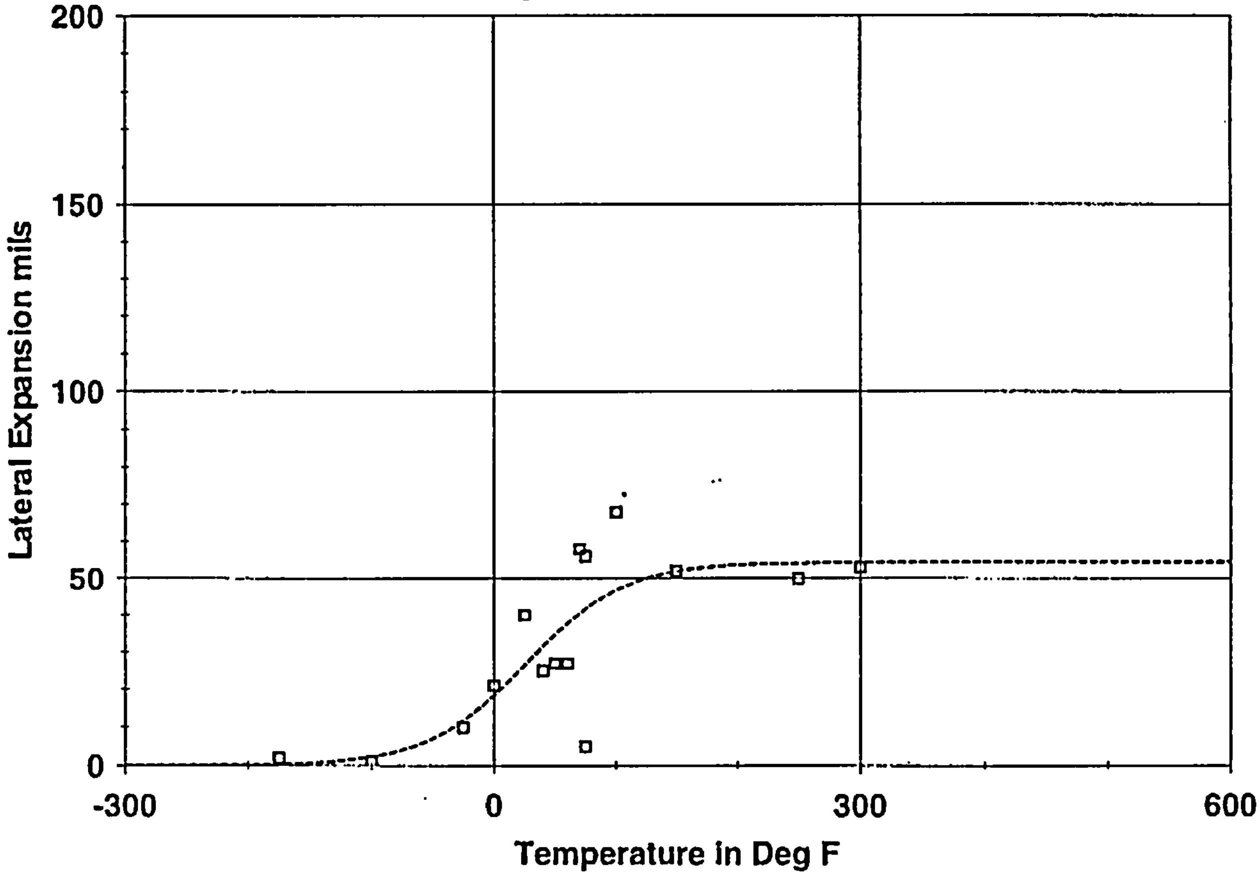
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=54.4 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=51.2 Deg F

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536

Orientation: NA Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-175.00	2.00	.37	1.63
-100.00	1.00	2.25	-1.25
-25.00	10.00	11.73	-1.73
.00	21.00	18.37	2.63
25.00	40.00	26.44	13.56
40.00	25.00	31.44	-6.44
50.00	27.00	34.65	-7.65
60.00	27.00	37.64	-10.64
70.00	58.00	40.37	17.63

CAPSULE U HEAT AFFECTED ZONE

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: U Fluence: n/cm^2

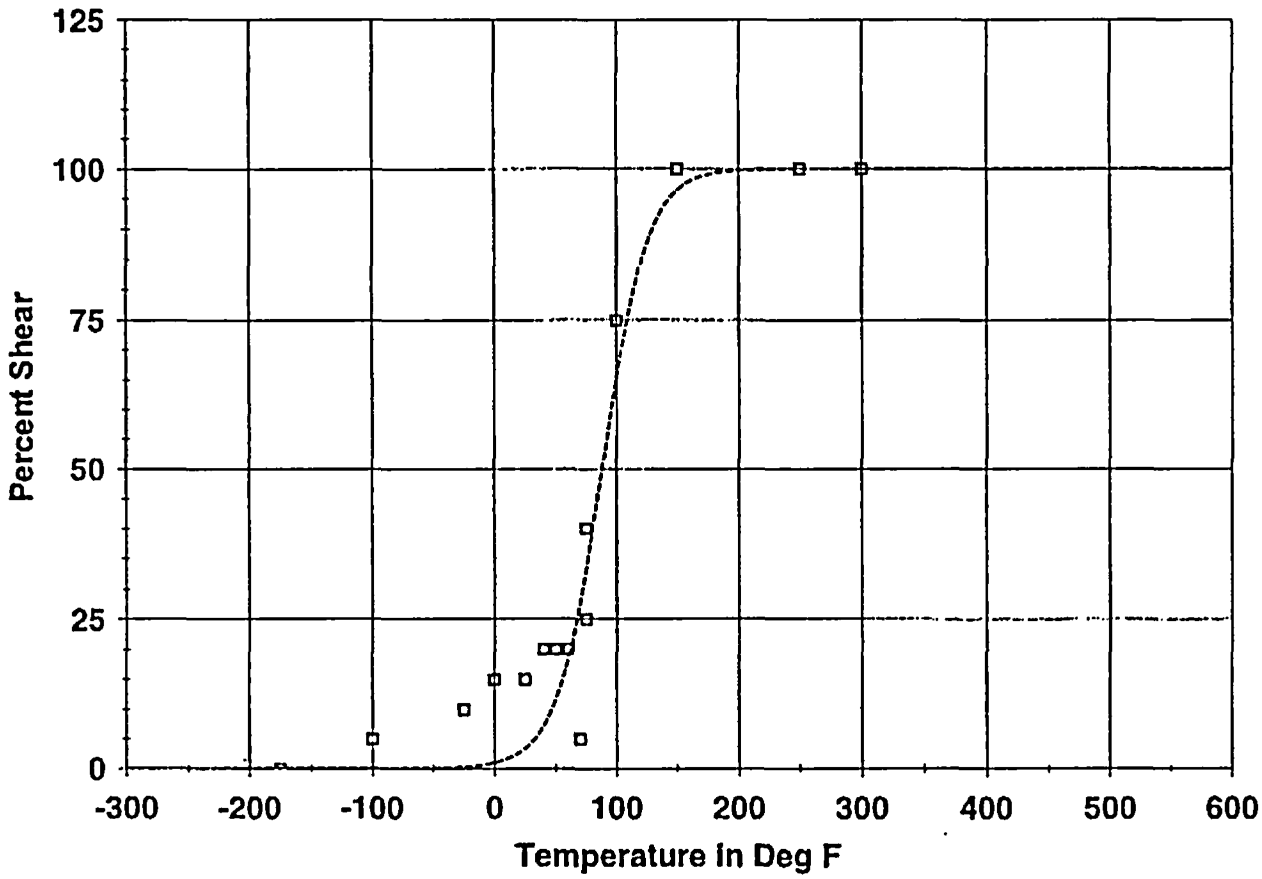
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
75.00	56.00	41.62	14.38
75.00	5.00	41.62	-36.62
100.00	68.00	46.68	21.32
150.00	52.00	51.92	.08
250.00	50.00	54.21	-4.21
300.00	53.00	54.36	-1.36

Correlation Coefficient = .782

CAPSULE U HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 03:33 PM
Page 1
Coefficients of Curve 2
A = 50. B = 50. C = 37.41 T0 = 88.1 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 88.1
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-175.00	.00	.00	.00
-100.00	5.00	.00	5.00
-25.00	10.00	.24	9.76
.00	15.00	.89	14.11
25.00	15.00	3.31	11.69
40.00	20.00	7.10	12.90
50.00	20.00	11.54	8.46
60.00	20.00	18.21	1.79
70.00	5.00	27.54	-22.54

CAPSULE U HEAT AFFECTED ZONE

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: U Fluence: n/cm^2

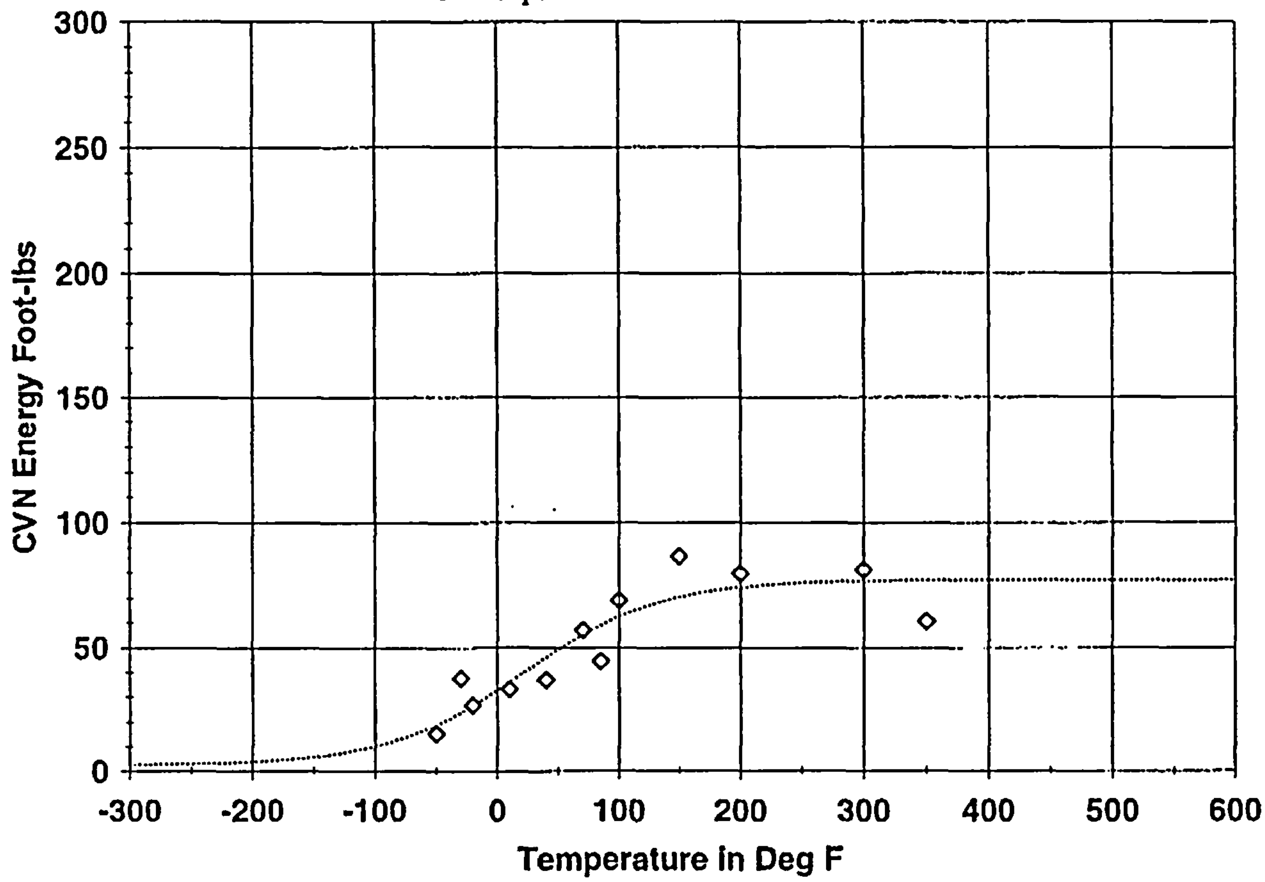
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
75.00	25.00	33.18	-8.18
75.00	40.00	33.18	6.82
100.00	75.00	65.39	9.61
150.00	100.00	96.48	3.52
250.00	100.00	99.98	.02
300.00	100.00	100.00	.00

Correlation Coefficient = .970

CAPSULE W HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 03:18 PM
Page 1
Coefficients of Curve 3
A = 39.6 B = 37.4 C = 111.37 T0 = 21.74 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=77.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-7.4 Deg F Temp@50 ft-lbs=53.6 Deg F
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-50.00	15.00	18.37	-3.37
-30.00	37.50	23.38	14.12
-20.00	26.50	26.20	.30
10.00	33.00	35.67	-2.67
40.00	37.00	45.68	-8.68
70.00	57.00	54.86	2.14
85.00	44.50	58.82	-14.32
100.00	69.00	62.27	6.73
150.00	86.50	70.20	16.30

CAPSULE W HEAT AFFECTED ZONE

Plant: Watts Bar 1   Material: SA508CL2   Heat: 527536
Orientation: NA   Capsule: W   Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
200.00	79.50	74.07	5.43
300.00	81.00	76.50	4.50
350.00	60.50	76.79	-16.29

Correlation Coefficient = .902

CAPSULE W HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 03:40 PM

Page 1

Coefficients of Curve 3

A = 31.8 B = 31.8 C = 108.76 T0 = 36.94 D = 0.00E+00

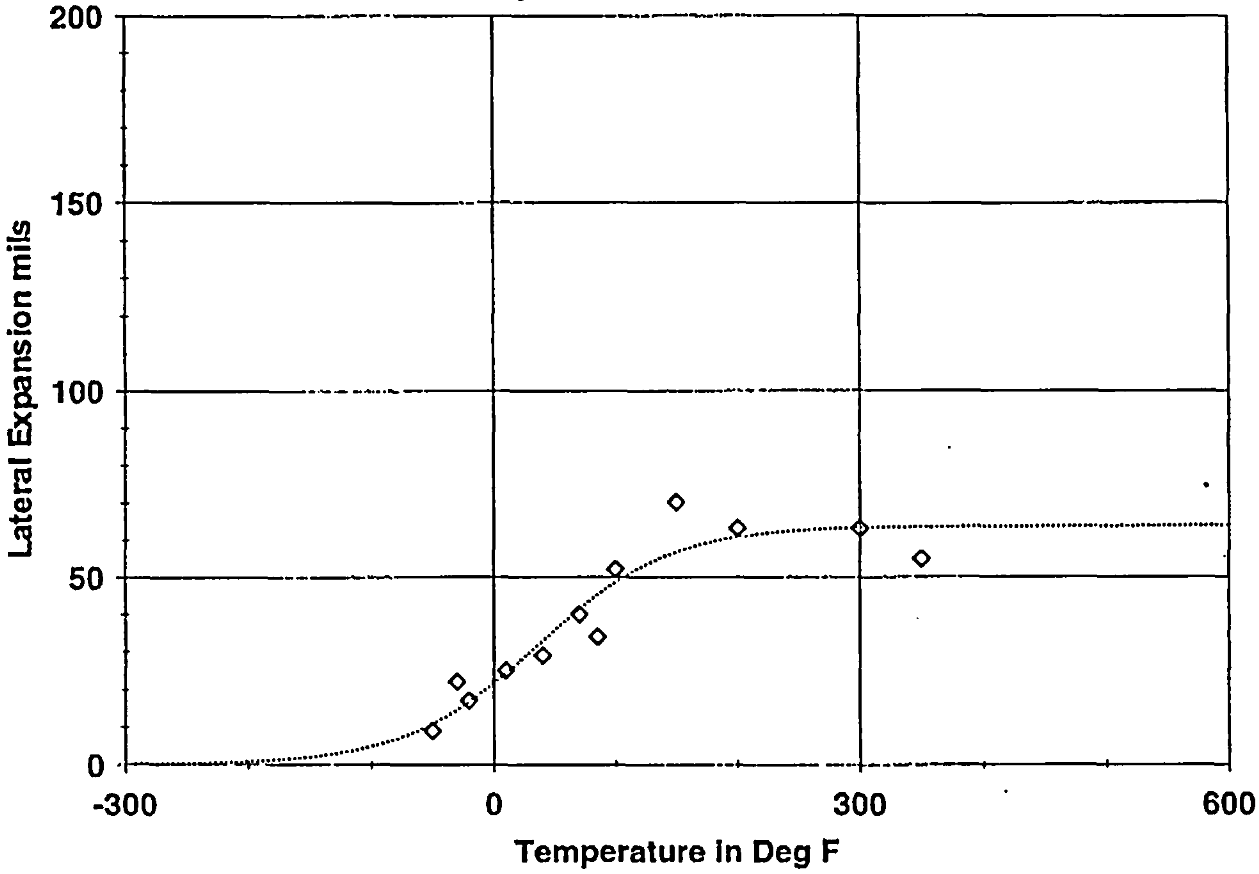
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=63.6 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=48.0 Deg F

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536

Orientation: NA Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-50.00	9.00	10.70	-1.70
-30.00	22.00	14.37	7.63
-20.00	17.00	16.52	.48
10.00	25.00	24.08	.92
40.00	29.00	32.70	-3.70
70.00	40.00	41.18	-1.18
85.00	34.00	45.00	-11.00
100.00	52.00	48.42	3.58
150.00	70.00	56.53	13.47

CAPSULE W HEAT AFFECTED ZONE

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: W Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
200.00	63.00	60.58	2.42
300.00	63.00	63.10	-.10
350.00	55.00	63.40	-8.40

Correlation Coefficient = .947

CAPSULE W HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 03:33 PM

Page 1

Coefficients of Curve 3

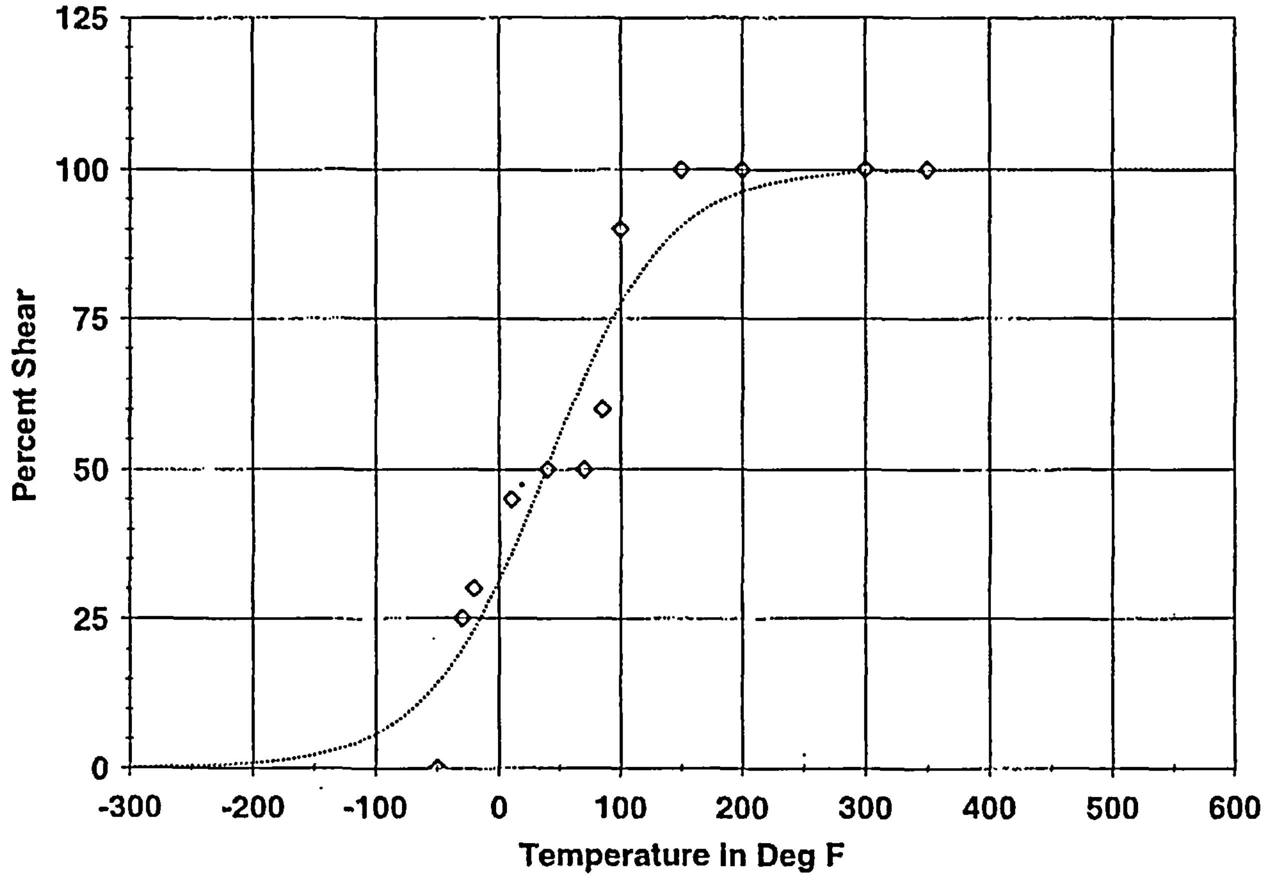
A = 50. B = 50. C = 99.03 T0 = 39.58 D = 0.00E+00

Equation is A + B * [Tanh((T-To)/(C+DT))]

Temperature at 50% Shear = 39.6

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536

Orientation: NA Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50.00	.00	14.07	-14.07
-30.00	25.00	19.70	5.30
-20.00	30.00	23.09	6.91
10.00	45.00	35.49	9.51
40.00	50.00	50.21	-.21
70.00	50.00	64.89	-14.89
85.00	60.00	71.45	-11.45
100.00	90.00	77.21	12.79
150.00	100.00	90.29	9.71

CAPSULE W HEAT AFFECTED ZONE

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: W Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
200.00	100.00	96.23	3.77
300.00	100.00	99.48	.52
350.00	100.00	99.81	.19

Correlation Coefficient = .963

CAPSULE X HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 03:18 PM

Page 1

Coefficients of Curve 4

A = 41.1 B = 38.9 C = 83.53 T0 = 43.04 D = 0.00E+00

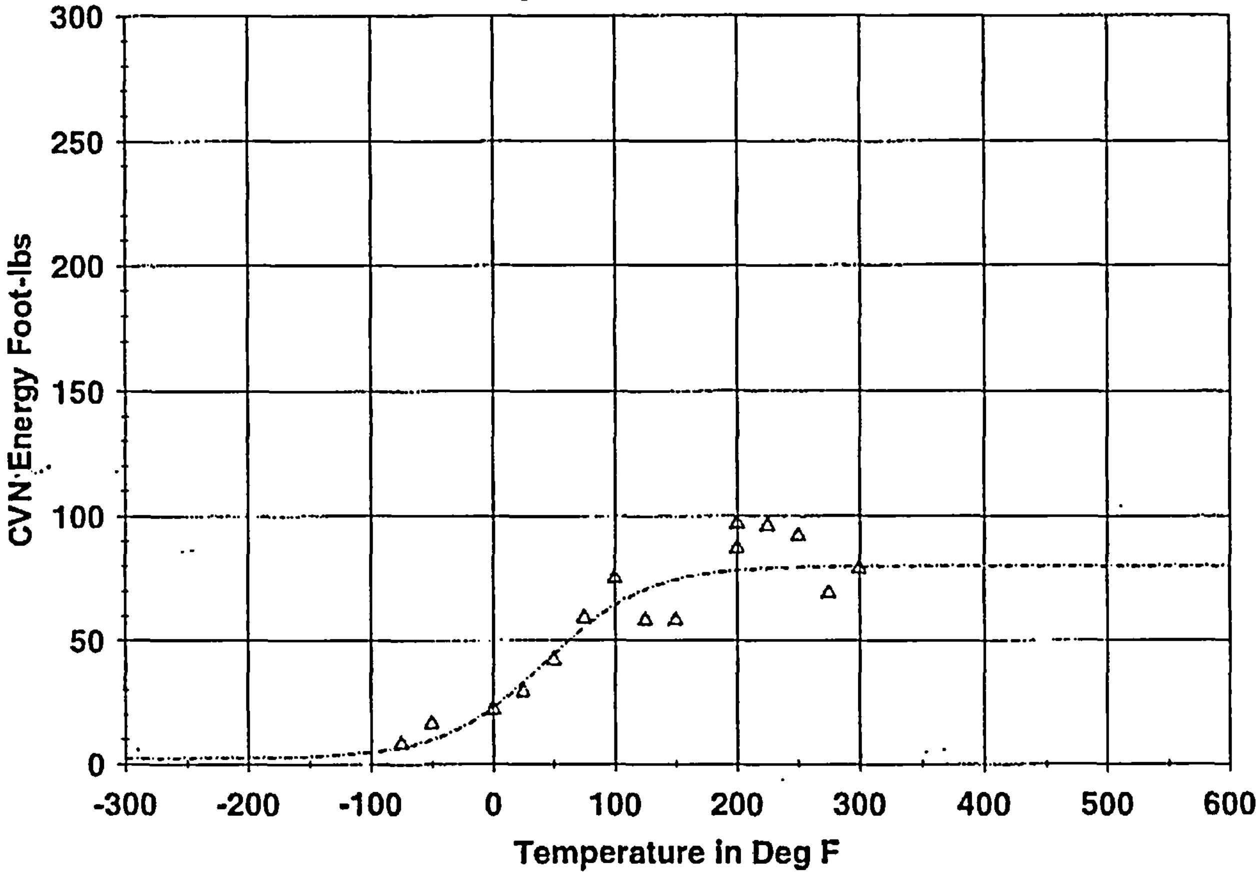
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=80.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=18.6 Deg F Temp@50 ft-lbs=62.5 Deg F

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536

Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-75.00	8.00	6.55	1.45
-50.00	16.00	9.77	6.23
.00	22.00	22.66	-.66
25.00	29.00	32.83	-3.83
50.00	42.00	44.33	-2.33
75.00	59.00	55.30	3.70
100.00	75.00	64.16	10.84
125.00	58.00	70.41	-12.41
150.00	58.00	74.42	-16.42

CAPSULE X HEAT AFFECTED ZONE

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: X Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
200.00	87.00	78.23	8.77
200.00	97.00	78.23	18.77
225.00	96.00	79.02	16.98
250.00	92.00	79.46	12.54
275.00	69.00	79.70	-10.70
300.00	79.00	79.83	-.83

Correlation Coefficient = .937

CAPSULE X HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 03:40 PM

Page 1

Coefficients of Curve 4

A = 28.15 B = 28.15 C = 79.27 T0 = 52.89 D = 0.00E+00

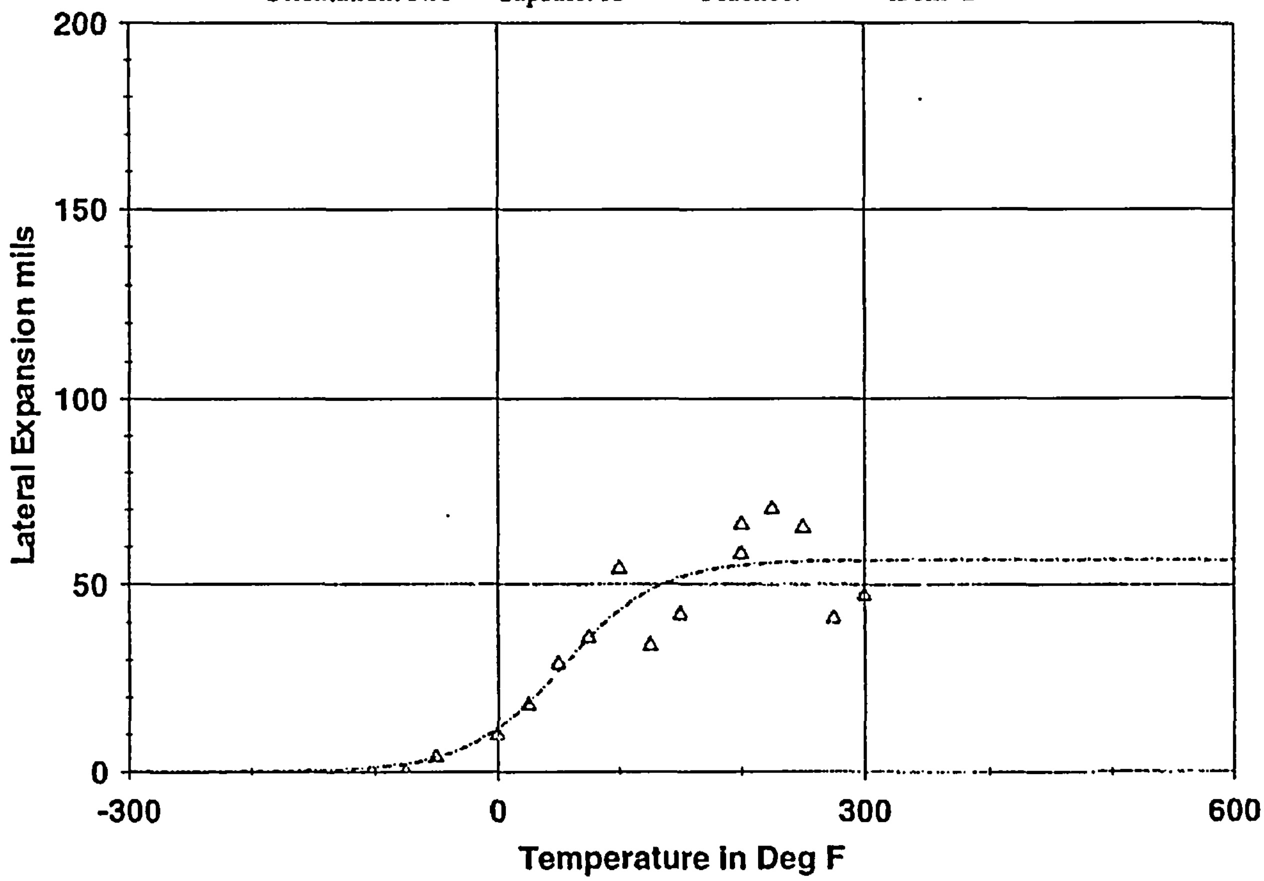
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=56.3 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=72.6 Deg F

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536

Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-75.00	.00	2.15	-2.15
-50.00	4.00	3.91	.09
.00	10.00	11.74	-1.74
25.00	18.00	18.64	-.64
50.00	29.00	27.13	1.87
75.00	36.00	35.81	.19
100.00	54.00	43.16	10.84
125.00	34.00	48.45	-14.45
150.00	42.00	51.83	-9.83

CAPSULE X HEAT AFFECTED ZONE

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: X Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
200.00	66.00	54.96	11.04
200.00	58.00	54.96	3.04
225.00	70.00	55.58	14.42
250.00	65.00	55.92	9.08
275.00	41.00	56.10	-15.10
300.00	47.00	56.19	-9.19

Correlation Coefficient = .915

CAPSULE X HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 02/09/2004 03:34 PM

Page 1

Coefficients of Curve 4

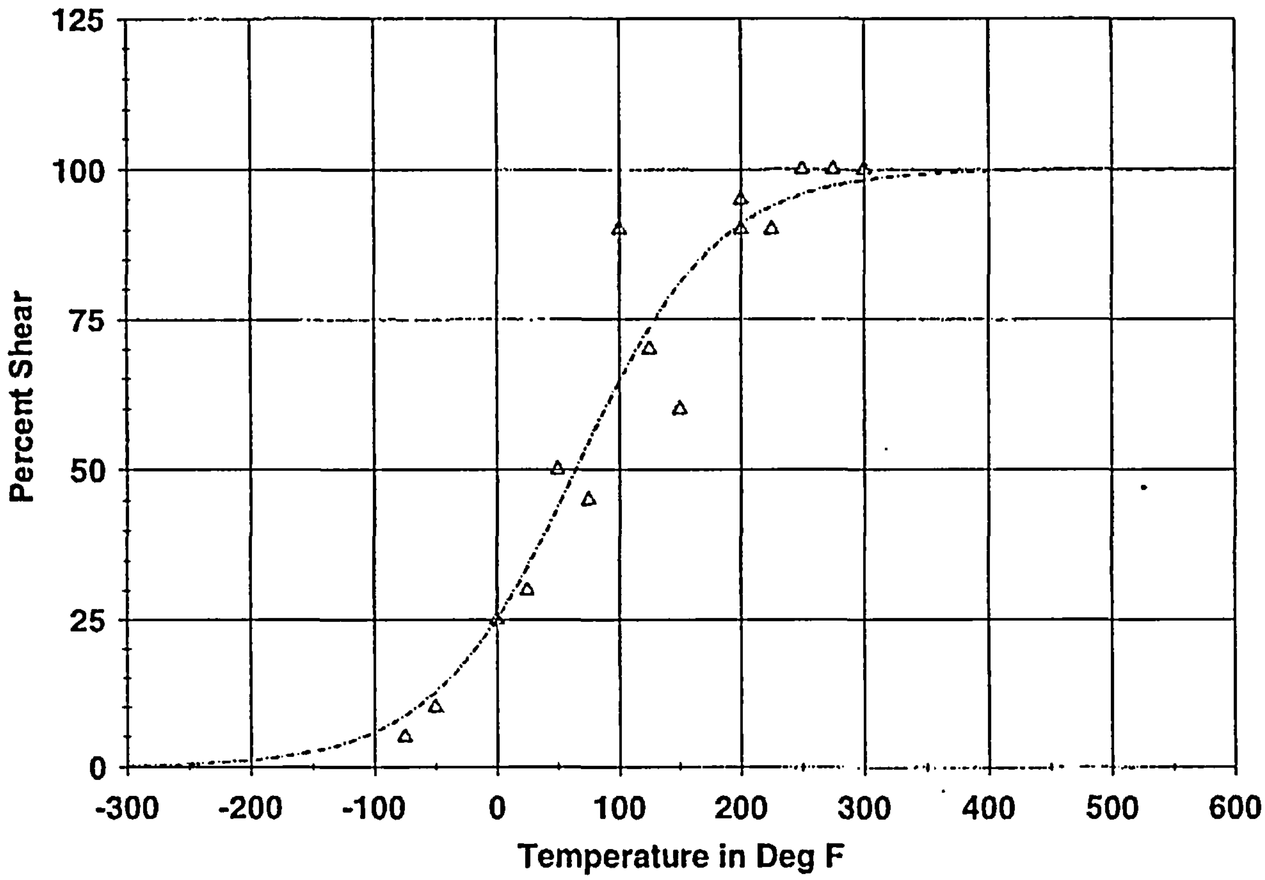
A = 50. B = 50. C = 117.85 T0 = 64.64 D = 0.00E+00

Equation is A + B * [Tanh((T-To)/(C+DT))]

Temperature at 50% Shear = 64.7

Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536

Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-75.00	5.00	8.55	-3.55
-50.00	10.00	12.50	-2.50
.00	25.00	25.03	-.03
25.00	30.00	33.79	-3.79
50.00	50.00	43.82	6.18
75.00	45.00	54.38	-9.38
100.00	90.00	64.57	25.43
125.00	70.00	73.58	-3.58
150.00	60.00	80.98	-20.98

CAPSULE X HEAT AFFECTED ZONE

Page 2
Plant: Watts Bar 1 Material: SA508CL2 Heat: 527536
Orientation: NA Capsule: X Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
200.00	95.00	90.86	4.14
200.00	90.00	90.86	-.86
225.00	90.00	93.83	-3.83
250.00	100.00	95.87	4.13
275.00	100.00	97.26	2.74
300.00	100.00	98.19	1.81

Correlation Coefficient = .960

APPENDIX D

WATTS BAR UNIT 1 SURVEILLANCE PROGRAM CREDIBILITY EVALUATION

INTRODUCTION:

Regulatory Guide 1.99, Revision 2, describes general procedures acceptable to the NRC staff for calculating the effects of neutron radiation embrittlement of the low-alloy steels currently used for light-water-cooled reactor vessels. Position C.2 of Regulatory Guide 1.99, Revision 2, describes the method for calculating the adjusted reference temperature and Charpy upper-shelf energy of reactor vessel beltline materials using surveillance capsule data. The methods of Position C.2 can only be applied when two or more credible surveillance data sets become available from the reactor in question.

To date there have been three surveillance capsules removed from the Watts Bar Unit 1 reactor vessel. To use these surveillance data sets, they must be shown to be credible. In accordance with the discussion of Regulatory Guide 1.99, Revision 2, there are five requirements that must be met for the surveillance data to be judged credible.

The purpose of this evaluation is to apply the credibility requirements of Regulatory Guide 1.99, Revision 2, to the Watts Bar Unit 1 reactor vessel surveillance data and determine if the Watts Bar Unit 1 surveillance data is credible.

EVALUATION:

Criterion 1: Materials in the capsules should be those judged most likely to be controlling with regard to radiation embrittlement.

The beltline region of the reactor vessel is defined in Appendix G to 10 CFR Part 50, "Fracture

Toughness Requirements", as follows:

> "the reactor vessel (shell material including welds, heat affected zones, and plates or forgings) that directly surrounds the effective height of the active core and adjacent regions of the reactor vessel that are predicted to experience sufficient neutron radiation damage to be considered in the selection of the most limiting material with regard to radiation damage."

The Watts Bar Unit 1 reactor vessel consists of the following beltline region materials:

- Intermediate Shell Forging 05
- Lower Shell Forging 04
- Intermediate to Lower Shell Circumferential Weld Seam (Heat # 895075).

At the time when the Watts Bar Unit 1 surveillance program material was selected it was believed that copper and phosphorus were the elements most important to embrittlement of the reactor vessel steels. However, the intermediate shell forging had the lowest initial USE of the vessel beltline materials and it was below the required 75 ft-lbs limit from 10CFR50 Appendix G. Thus it was selected as the surveillance base metal.

The weld material in the Watts Bar Unit 1 surveillance program was made of the same wire as the reactor vessel beltline weld, thus it was chosen as the surveillance weld material.

Hence, Criterion 1 is met for the Watts Bar Unit 1 reactor vessel.

Criterion 2: Scatter in the plots of Charpy energy versus temperature for the irradiated and unirradiated conditions should be small enough to permit the determination of the 30 ft-lb temperature and upper shelf energy unambiguously.

Based on engineering judgment, the scatter in the data presented in these plots is small enough to permit the determination of the 30 ft-lb temperature and the upper shelf energy of the Watts Bar Unit 1 surveillance materials unambiguously. Hence, the Watts Bar Unit 1 surveillance program meets this criterion.

Criterion 3: When there are two or more sets of surveillance data from one reactor, the scatter of ΔRT_{NDT} values about a best-fit line drawn as described in Regulatory Position 2.1 normally should be less than 28°F for welds and 17°F for base metal. Even if the fluence range is large (two or more orders of magnitude), the scatter should not exceed twice those values. Even if the data fail this criterion for use in shift calculations, they may be credible for determining decrease in upper shelf energy if the upper shelf can be clearly determined, following the definition given in ASTM E185-82.

The functional form of the least squares method as described in Regulatory Position 2.1 will be utilized to determine a best-fit line for this data and to determine if the scatter of these ΔRT_{NDT} values about this line is less than 28°F for welds and less than 17°F for the plate.

The Watts Bar intermediate to lower circumferential weld will be evaluated for credibility. This weld is made from weld wire heat 895075. This weld metal is also contained in the Catawba Unit 1 and McGuire Unit 2 surveillance programs. Since the welds in question utilize data from other surveillance programs, the recommended NRC methods for determining credibility will be followed. The NRC methods were presented to industry at a meeting held by the NRC on February 12 and 13, 1998. At this meeting the NRC presented five cases. Of the five cases, Case 4 most closely represents the situation listed above for Watts Bar surveillance weld metal. Note, for the plate materials, the straight forward method of Regulatory Guide 1.99, Revision 2 will be followed. Note, for the forging material, the straight forward method of Regulatory Guide 1.99, Revision 2 will be followed.

First, NRC Case 4 will be evaluated for the Watts Bar surveillance weld metal, "Surveillance Data Available from Plant and Other Sources".

TABLE D-1
Surveillance Data - Normalization for Credibility Determination (when all data is being used)

Capsule	Vessel CF[a] (°F)	Surv. Material CF[a] (°F)	Irradiation Temp. ($T_{capsule}$)[b]	Fluence ($x 10^{19}$)	Fluence Factor (FF)	Measured ΔRT_{NDT}	Temperature Adjusted (560°F)[b]	Ratio Chemistry Adjusted ΔRT_{NDT}[a]
WB1 - U	54.0	41.0	560°F	0.447	0.776	0.0[c]°F	0.0°F	0.0°F
WB1 - W	54.0	41.0	560°F	1.08	1.02	30.5°F	30.5°F	40.26°F
WB1 - X	54.0	41.0	560°F	1.71	1.15	25.8°F	25.8°F	34.06°F
Cat.1 – Z	54.0	68.0	553°F	0.2993	0.670	1.91°F	0.0[d]°F	0.00°F
Cat.1 – Y	54.0	68.0	553°F	1.318	1.077	17.79°F	10.79°F	8.52°F
Cat.1 – V	54.0	68.0	553°F	2.334	1.229	26.5°F	19.5°F	15.41°F
MG2 – V	54.0	54.0	554°F	0.323	0.689	38.51°F	32.51°F	32.51°F
MG2 – X	54.0	54.0	554°F	1.47	1.11	35.93°F	29.93°F	29.93°F
MG2 – U	54.0	54.0	554°F	2.04	1.19	23.81°F	17.81°F	17.81°F
MG2 - W	54.0	54.0	554°F	3.07	1.30	43.76°F	37.76°F	37.76°F

Notes:
(a) Ratios equal 1.32 (Watts Bar), 0.79 (Catawba 1), and 1.0 (McGuire 2).
(b) Normalized to an average operating temperature 560°F (The Watts Bar Reactor Vessel).
(c) Actual value -6.4°F. For conservatism zero will be used.
(d) After the temperature adjustment, the Adjusted ?RT_{NDT} is less than zero. For conservatism zero will be used.

Credibility assessment - Watts Bar Data Only:

Assume the following for Watts Bar, the plant being assessed:

- Weld Heat # 895075 is in the surveillance program and in the vessel. The cold inlet temperature is equal to 560°F.
- The Best Estimate chemistry for heat # 895075 is:Cu = 0.04%, Ni = 0.73%
  This equates to a Chemistry Factor of: CF = 54.0°F

The data most representative for Watts Bar is that from Watts Bar since the irradiation environment of the surveillance capsules and the vessel are the same. The data requires the least adjustments. Watts Bar data should be examined independently to determine credibility.

Since all data is from one source (Watts Bar), then plot the measure ?RT_{NDT} versus FF and determine the best fit line.

TABLE D-2
Determination of Surveillance Weld CF Watts Bar Unit 1 Data Only

Material	Capsule	Capsule f[a] (x 10^{19})	FF	ΔRT_{NDT}	FF*ΔRT_{NDT}	FF^2
Watts Bar	WB1 - U	0.447	0.776	0.0[b]	0.00	0.602
Surveillance	WB1 - W	1.08	1.02	30.5	31.11	1.04
Weld Material	WB1 - X	1.71	1.15	25.8	29.67	1.32
				SUM:	60.78	2.962
	$CF_{Surv. Weld} = \Sigma(FF * RT_{NDT}) \div \Sigma(FF^2) = (60.78°F) \div (2.962) = 20.5°F$					

(a) Units are n/cm² (E > 1.0 MeV).
(b) Actual value is -6.4, but for conservatism(i.e. a higher CF) a value of zero is used.

Slope of best fit line = 20.5°F

The Scatter above the best fit line is given in Table D-3:

TABLE D-3
Watts Bar Surveillance Capsule Data Only

Capsule	CF (°F)	Irradiation Temperature ($T_{capsule}$)	Fluence[(a)] ($x 10^{19}$)	Fluence Factor (FF)	Measured ΔRT_{NDT}	Predicted[(b)] ΔRT_{NDT} from Best Fit Line	(Measured - Predicted) ΔRT_{NDT}
WB1 - U	20.5	560°F	0.447	0.776	0.0[(c)]	15.9°F	-15.9°F
WB1 - W	20.5	560°F	1.08	1.02	30.5	20.9°F	9.6°F
WB1 - X	20.5	560°F	1.71	1.15	25.8	23.6°F	2.2°F

(a) Units are n/cm^2 (E > 1.0 MeV).
(b) Where predicted ΔRT_{NDT} = ($Slope_{best\ fit}$) * (Fluence Factor)
(c) Actual value is -6.4, but for conservatism (i.e. a higher CF) a value of zero is used.

Data is credible since the scatter is less than 28°F for all three surveillance specimens.

Credibility Assessment - All Weld Data:

The data from all sources should also be considered

Since data are from multiple sources the data must be adjusted for chemical composition and irradiation environment differences and then determine the "ratio and temperature" adjusted slope of the best fit line.

For credibility determination, data are normalized to the mean chemical composition and temperature of the Watts Bar surveillance specimens.

TABLE D-4
All Surveillance Capsule Weld Data

Material	Capsule	Capsule f[a] (x 10^{19})	FF[b]	Ratio Temperature Adjusted ΔRT_{NDT}[c]	FF*ΔRT_{NDT}	FF^2
Surv. Weld	WB1 - U	0.447	0.776	0.0	0.00	0.602
Material	WB1 - W	1.08	1.02	40.26	41.07	1.04
	WB1 - X	1.71	1.15	34.06	39.17	1.32
	Cat.1 – Z	0.2993	0.670	0.0	0.000	0.449
	Cat.1 – Y	1.318	1.077	8.52	9.176	1.160
	Cat.1 – V	2.334	1.229	15.41	18.927	1.510
	MG2 – V	0.323	0.689	32.51	22.399	0.475
	MG2 – X	1.47	1.11	29.93	33.22	1.23
	MG2 – U	2.04	1.19	17.81	21.19	1.42
	MG2 - W	3.07	1.30	37.76	49.09	1.69
				SUM:	234.242	10.896
	$CF_{Surv.\ Weld} = \Sigma(FF * RT_{NDT}) \div \Sigma(FF^2) = (234.242) \div (10.896) = 21.5°F$					

Notes:
(a) Calculated fluence in units of n/cm^2 (E > 1.0 MeV).
(b) FF = fluence factor = $f^{(0.28 - 0.1*\log f)}$.
(c) From Table D-1; [°F].

The slope of the best fit line = 21.5°F

TABLE D-5
Best Fit of all Weld Metal Surveillance Data Available

Capsule	CF (°F)	Irradiation Temperature ($T_{capsule}$)	Fluence ($x 10^{19}$)[a]	Fluence Factor (FF)	Ratio Temperature Adjusted ΔRT_{NDT}	Predicted[b] ΔRT_{NDT} from Best Fit Line	(Measured - Predicted) ΔRT_{NDT}
WB1 - U	21.5	560°F	0.447	0.776	0.0°F	16.68°F	-16.7°F
WB1 - W	21.5	560°F	1.08	1.02	40.26°F	21.93°F	18.3°F
WB1 - X	21.5	560°F	1.71	1.15	34.06°F	24.73°F	9.3°F
Cat.1 – Z	21.5	553°F	0.2993	0.670	0.0°F	14.41°F	-14.4°F
Cat.1 – Y	21.5	553°F	1.318	1.077	8.52°F	23.16°F	-14.6°F
Cat.1 – V	21.5	553°F	2.334	1.229	15.41°F	26.42°F	-11.0°F
MG2 – V	21.5	554°F	0.323	0.689	32.51°F	14.81°F	17.7°F
MG2 – X	21.5	554°F	1.47	1.11	29.93°F	23.87°F	6.1°F
MG2 – U	21.5	554°F	2.04	1.19	17.81°F	25.59°F	-7.8°F
MG2 - W	21.5	554°F	3.07	1.30	37.76°F	27.95°F	9.8°F

(a) Units are n/cm^2 (E > 1.0 MeV).
(b) Where predicted ΔRT_{NDT} = ($Slope_{best fit}$) * (Fluence Factor)

Data is credible since the scatter is less than 28°F for all surveillance specimens.

In summary, the measured weld data is within acceptable range regardless of whether Watts Bar data is evaluated stand-alone or with the surveillance data from Catawba 1 and McGuire 2. Therefore, weld data meets this criteria, and the surveillance program weld metal CF to be used in calculations is 21.5°F and is based on all available surveillance data.

Credibility Assessment – Forging Material:

Now that the Weld Metal has been evaluated for credibility, the surveillance Forging material must be evaluated. From Table D-6 the calculated CF values from surveillance data for the intermediate shell forging 05 is 90.3°F.

TABLE D-6

Calculation of Chemistry Factors using Watts Bar Unit 1 Surveillance Capsule Data

Material	Capsule	Capsule f[a]	FF[b]	ΔRT_{NDT}[c]	FF*ΔRT_{NDT}	FF^2
Inter. Shell	U	0.447	0.776	98.3	76.281	0.602
Forging 05	W	1.08	1.02	111.4	113.63	1.04
(Tangential)	X	1.71	1.15	94.7	108.91	1.32
Inter. Shell	U	0.447	0.776	28.7	22.271	0.602
Forging 05	W	1.08	1.02	79.0	80.58	1.04
(Axial)	X	1.71	1.15	115.9	133.29	1.32
				SUM:	534.962	5.924
	$CF_{05} = \Sigma(FF * RT_{NDT}) \div \Sigma(FF^2) = (534.962) \div (5.924) = 90.3°F$					

(a) Calculated fluence in units of n/cm^2 (E > 1.0 MeV).

(b) FF = fluence factor = $f^{(0.28 - 0.1*\log f)}$.

(c) From Appendix C; [°F].

TABLE D-7

Predicted Versus Best-Estimate ΔRT_{NDT} Values for the Watts Bar Unit 1 Surveillance Forging Data

Material	Capsule	CF	FF	Predicted ΔRT_{NDT}	Measured ΔRT_{NDT}	Change in ΔRT_{NDT} (Predicted - Measured)
Intermediate Shell	U	90.3°F	0.776	70.1	98.3	-28.2
Forging 05	W	90.3°F	1.02	92.1	111.4	-19.3
(Tangential)	X	90.3°F	1.15	103.8	94.7	9.1
Intermediate Shell	U	90.3°F	0.776	70.1	28.7	41.4
Forging 05	W	90.3°F	1.02	92.1	79.0	13.1
(Axial)	X	90.3°F	1.15	103.8	115.9	-12.1

From Table D-7 above, 3 out of 6 data points exceeds the +/- 17°F scatter-band and is therefore deemed not-credible.

Criterion 4: The irradiation temperature of the Charpy specimens in the capsule should match the vessel wall temperature at the cladding/base metal interface within +/- 25°F.

The capsule specimens are located in the reactor between the neutron pad and the vessel wall and are positioned opposite the center of the core. The test capsules are in baskets attached to the neutron pad. The location of the specimens with respect to the reactor vessel beltline provides assurance that the reactor vessel wall and the specimens experience equivalent operating conditions such that the temperatures will not differ by more than 25°F. Hence, this criterion is met.

Criterion 5: The surveillance data for the correlation monitor material in the capsule should fall within the scatter band of the database for that material.

The Watts Bar Unit 1 surveillance program does not contain correlation monitor material. Therefore, this criterion is not applicable to the Watts Bar Unit 1 surveillance program.

CONCLUSION:

Based on the preceding responses to all five criteria of Regulatory Guide 1.99, Revision 2, Section B and 10 CFR 50.61, the Watts Bar Unit 1 surveillance plate and weld data is credible.